PASSIVE AND ACTIVE TARGET DETECTION

by

Suleman Nadeem Lehrasab

BEE193022

A Project Report submitted to the
DEPARTMENT OF ELECTRICAL ENGINEERING
in partial fulfillment of the requirements for the degree of
BACHELORS OF SCIENCE IN ELECTRICAL ENGINEERING

Faculty of Engineering
Capital University of Science & Technology,
Islamabad

July, 2023

“…Know that if the whole world were to gather together in order to help you, they would not be able to help you except if God had written so. And if the whole world were to gather together in order to harm you, they would not harm you except if God had written so. The pens have been lifted, and the pages are dry.”

-Narrated by at-Tirmidhi – ḥasan-ṣaḥeeḥ

This thesis is sincerely dedicated to my father, whose unwavering strength has taught me the true meaning of resilience amidst life's hardships.

DECLARATION

It is declared that this is an original piece of my own work, except where otherwise acknowledged in text and references. This work has not been submitted in any form for another degree or diploma at any university or other institution for tertiary education and shall not be submitted by me in future for obtaining any degree from this or any other University or Institution.

Suleman Nadeem Lehrasab
BEE193022

July, 2023

CERTIFICATE OF APPROVAL

It is certified that the project titled “Passive and Active Target Detection” carried out by Suleman Nadeem Lehrasab, Reg. No. BEE193022, under the supervision of Dr. Aamer Iqbal Bhatti and Mr. Umar Maqbool, Capital University of Science & Technology, Islamabad, is fully adequate, in scope and in quality, as a final year project for the degree of BS Electrical Engineering.

Supervisor: -------------------------------------
Mr. Umar Maqbool
Assistant Professor
Department of Electrical Engineering
Faculty of Engineering
Capital University of Science & Technology, Islamabad

HoD: -------------------------------------
Dr. Noor Mohammad Khan
Professor
Department of Electrical Engineering
Faculty of Engineering
Capital University of Science & Technology, Islamabad

ACKNOWLEDGMENT

I extend my sincere gratitude to Dr. Aamer Iqbal Bhatti and Mr. Umar Mqbool, my supervisor, for his invaluable guidance and unwavering support throughout this journey. His expertise and encouragement have been instrumental in shaping my academic growth and research endeavors.

ABSTRACT

This project focuses on active and passive detection techniques for target localization. In today's age of dense RF environments, active and passive detection techniques have become even more critical. There is a lot of literature present on Active and Passive detection techniques independently, however, the comparative analysis of these techniques, their integration, and their combined benefits is an area that has received relatively less attention. This project aims to explore and compare the performance of these two detection techniques, providing valuable insights into their respective advantages and limitations in target localization applications. Passive detection involves the utilization of a switched array based on amplitude measurements to determine AOA of the target signal. By analyzing the relative signal strengths received at different antenna elements, the AOA can be estimated without emitting any additional signals. On the other hand, active detection relies on RADAR technology to actively emit signals and measure the time delay of the echoes reflected from the target. Hardware and software for both these systems has been integrated and developed for this project. The project yielded several significant findings. It revealed that active detection excelled in terms of accuracy and resolution, while passive detection offered covert operation capabilities. The integration of both techniques provided complementary information, enhancing the overall detection capabilities. However, limitations were identified for both the systems. For passive detection the detectability of low SNR RF signals proved to be a challenge which can lead to range limitations. In the case of Active detection, hefty peak power requirements for transmission signal, and an inherent incapacity to shield RF presence was the biggest challenge. The project emphasized the importance of considering the sensing environment when determining the most suitable technique for specific applications. According to the results, active detection methods are better suited for targets which are not emitting any RF signal, and when the user does not intend to shield their RF presence. Passive detection methods are better suited to targets which emit RF signals, and when users want to shield their RF presence.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS/ABBREVIATIONS

RF	Radio Frequency
USRP	Universal Software Radio Peripheral
AOA	Angle of Arrival
RADAR	Radio Detection and Ranging
DF	Direction Finding
CIDF	Correlative Interferometer Direction Finder
LPDA	Log-Periodic Dipole Array
SDG	Sustainable Development Goals
LFM	Linear Frequency Modulation
FMCW	Frequency Modulated Continuous Wave
CW	Continuous Wave
SAR	Synthetic Aperture Radar
CPI	Coherent Processing Interval
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
PA	Power Amplifier
LNA	Low Noise Amplifier
FF	Fixed Frequency
FIFO	First In First Out
FFT	Fast Fourier Transform
ADC	Analog to Digital Convertor

Chapter 1

INTRODUCTION

The following report presents a comprehensive investigation into the realm of active and passive detection techniques and their comparative analysis. The aim of this study is to explore the strengths, limitations, and potential synergies between these two distinct approaches in target detection and localization. By examining the existing literature, conducting experimental evaluations, and analyzing the performance metrics, this report provides valuable insights into the respective merits and challenges of active and passive detection. Furthermore, it seeks to shed light on the potential benefits of integrating these techniques to harness their complementary capabilities. The findings presented herein contribute to a deeper understanding of the practical implications and optimization of active and passive detection methods for a diverse range of applications. Throughout this text, passive detection can be referred to as DF and active detection can be referred to as RADAR, because they are based on those underlying technologies.

1.1 Overview

This project aims to explore and compare the performance of passive and active detection, providing valuable insights into their respective advantages and limitations in target localization applications, and evaluating the importance of considering the sensing environment when determining the most suitable technique for the specific applications.

1.2 Project Idea

Comparing active and passive detection techniques is of paramount importance due to several reasons. Firstly, it allows for a comprehensive understanding of the strengths and limitations of each technique individually. By comparing their performance metrics, such as accuracy, range, cost, and vulnerability to interference, researchers and practitioners can make informed decisions about the most suitable technique for specific applications.

Secondly, comparing these techniques facilitates the identification of potential synergies and the exploration of hybrid solutions. Active and passive detection methods have complementary characteristics.

Active detection provides direct control over emitted signals, enabling precise measurements, while passive detection offers covert operations without emitting detectable signals. Integrating these techniques can harness the benefits of both approaches, enhancing accuracy, range, robustness, and adaptability in dynamic environments.

1.3 Purpose of the Project

A hybrid solution that combines active and passive detection techniques can overcome the limitations of each method individually. For instance, active detection can compensate for the limited range of passive detection, while passive detection can aid in covert operations and reduce the vulnerability to interference.

Such a hybrid approach can provide a more comprehensive and robust solution for target detection, localization, and tracking, particularly in challenging environments. Furthermore, a hybrid solution can also offer flexibility and adaptability. Depending on the specific requirements and constraints of a given situation, the balance between active and passive techniques can be adjusted dynamically. This adaptability allows for optimal performance, considering factors such as power consumption, detection range, stealth requirements, and environmental conditions.

In conclusion, comparing active and passive detection techniques is crucial to understand their individual merits and limitations. A hybrid solution combining both techniques offer the potential to leverage their respective strengths, overcome limitations, and provide a more comprehensive and adaptable approach to target detection and localization in diverse applications.

1.4 Project Specifications

The active and passive systems designed have the following specifications, given in table 1-1.

Table 1-1: Project Specifications

Specification	**DF**	**RADAR**
Transmitting signal	None	Modulated pulse
Receiving signal	RF emitting from target	Echo of Tx Signal
Signal processing domain	Frequency domain	Time domain
Hardware configuration	Switched Circular Array	Tx and Rx Antennas
Min. detectable signal	-100dBm	-120dBm
Target detection	AoA	Geolocation
Operating frequency range	800MHz-2400MHz	2.5GHz (FF)

1.5 Applications of the Project

Active and passive target detection have many applications in commercial and military fields. Some of which are listed below.

1.5.1 Direction Finding

1. **Radio Frequency (RF) Monitoring:** DF techniques are employed for RF monitoring to detect, locate, and track sources of electromagnetic signals. This is crucial for spectrum management, identifying unauthorized transmissions, and ensuring compliance with regulations.
2. **Signal Intelligence (SIGINT):** DF plays a vital role in SIGINT operations, enabling the interception and analysis of communication signals for intelligence gathering, threat assessment, and monitoring of adversaries' activities.

3. **Navigation and Localization:** DF techniques are utilized in navigation systems, such as VHF Omnidirectional Range and Automatic Direction-Finding systems, to determine the direction of radio beacons and aids in aircraft and maritime navigation.
4. **Search and Rescue:** DF techniques are instrumental in search and rescue operations, helping to locate distress signals from emergency beacons, such as Emergency Position Indicating Radio Beacons.

1.5.2 Radar

1. **Air Traffic Control:** Radar is extensively used in air traffic control systems for aircraft surveillance, collision avoidance, and airspace management. It provides real-time information on aircraft position, velocity, and altitude.
2. **Weather Monitoring:** Radar plays a critical role in weather monitoring and forecasting. Weather radars can detect and track precipitation, measure rainfall intensity, identify severe weather phenomena (like tornadoes or thunderstorms), and assist in issuing timely weather warnings.
3. **Military Applications:** Radar is extensively used in military applications for target detection, tracking, and weapon guidance. It aids in surveillance, missile defense systems, aircraft navigation, and battlefield situational awareness.
4. **Automotive Safety:** Radar technology is incorporated into advanced driver-assistance systems for collision avoidance, adaptive cruise control, and blind-spot detection in vehicles. It enables sensing the environment, detecting obstacles, and providing warnings or automatic interventions to enhance road safety. Millimeter wave radars are used in for automotive applications due to high resolution.

1.6 Project Plan

The project plan can be divided into two categories, the project tasks, and the project timeline. The details for both are given in the sections below.

1.6.1 Project Milestones

The project milestones are divided into 14 tasks, details of which are given in Table 1-2.

Table 1-1: Project Plan

S#	Tasks	Resource Person
1	Simulating Systems requirements	Suleman
2	DF software development - switched array FFTs	Suleman
3	Radar Waveform Analysis	Suleman
4	Radar Hardware integration	Suleman
5	DF hardware integration	Suleman
6	Radar Software development - Intra pulse modulation	Suleman
7	Radar Software development – CPI	Suleman
8	DF software development - interpolation and Regression	Suleman
9	Radar Software development - Pulse Compression	Suleman
10	DF software development - AoA estimation	Suleman
11	Radar Software development - Range Estimation	Suleman
12	Creating GUI	Suleman
13	Comprehensive Testing	Suleman
14	Compiling and Analyzing Results	Suleman

1.6.2 Project Timeline

Project timeline can be seen in Figure 1-1, it has been divided into 14 different tasks according to the project plan given in Table 1-2. All assigned tasks of the project were completed successfully in the given timeline.

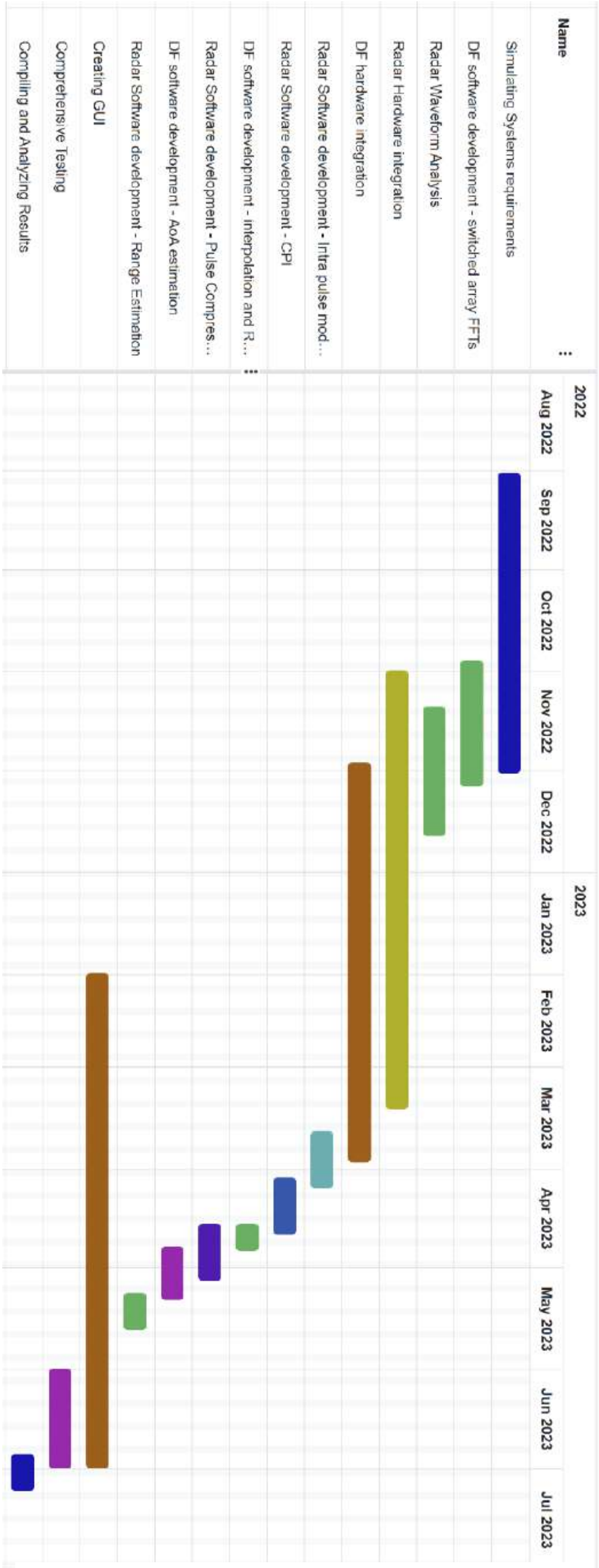


Figure 1-1: Project Timeline

1.7 Sustainable Development Goals

This project covers 3 out of 17 SDG set by the United Nations. The details are given in Table 1-3.

Table 1-2: SDG

Goal No.	Goal	How it can be achieved
9	Industry Innovation and Infrastructure	Analysing active and passive techniques together can lead to the development of hybrid architecture which is relatively novel domain and has the capacity to create an entirely new industrial sector while driving the existing industrial sector of RF towards innovation and novelty.
11	Sustainable cities and communities	Active and passive techniques are used for the safety and betterment of communities, such as automotive radars in autonomous vehicles, and drone detection at airports to ensure safety of aircraft and its passengers.
16	Peace, justice, and strong institutions	Active and passive detection is thoroughly used by law enforcement agencies for Signal intelligence applications which inherently make society safer for everyone.

1.8 Report Organization

The report is divided into 6 chapters, which cover the following:

- **Chapter 1: Introduction** covers the introduction, and project overview while also discussing the key deliverables of the project.
- **Chapter 2: Literature Review** focuses on the existing work done on RADAR and DF, and how it is relevant to this specific project.
- **Chapter 3: Project Design and Implementation** describes, in depth, the hardware & software design and architecture of the entire system.
- **Chapter 4: Tools and Techniques** summarizes all hardware and software tools used in this project, and how they are being utilized in this project.
- **Chapter 5: Project Results and Evaluation** presents and explains the testing results of the system and compares them with the project specifications.
- **Chapter 6: Conclusion and Future work** draws conclusion on the testing results and comments on the shortcomings.

Chapter 2

LITERATURE REVIEW

This chapter presents a literature review focusing on the concepts, fundamental principles, and applications of active and passive systems.

2.1 Pulsed Radar

Pulse radar is a fundamental and widely used technology in the field of radar systems. It operates by emitting short-duration pulses of electromagnetic energy and analyzing the echoes reflected from targets. This brief introductory section provides an overview of pulse radar technology, highlighting its key principles and applications.

2.1.1 Fundamental Principle

Radar technology is a system that uses radio waves to detect, locate, track, and measure the properties of objects in its vicinity. Radar works by transmitting radio waves towards a target and detecting the echoes reflected back from the object. The time delay, frequency shift, and amplitude of the received echoes provide information about the target's distance, velocity, and other properties. A typical radar system consists of a transmitter that generates radio waves, an antenna(s) to transmit and receive signals, a receiver to process the received echoes, and signal processing algorithms to extract useful information from the echoes [1]. Various techniques are employed in radar systems to enhance performance and extract valuable information. These include pulse compression, which improves range resolution; phased array technology for electronically steering the radar beam; and Doppler processing, which enables measurement of target velocity. There are several common radar techniques used in various applications. Here are some of the most employed radar techniques:

1. **Continuous Wave (CW) Radar:** CW radar emits a continuous wave of radio frequency energy and measures the frequency shift of the received signal to determine the velocity of a target. It is commonly used for speed detection and short-range applications.
2. **Pulse-Doppler Radar:** Pulse-Doppler radar utilizes short pulses of radio frequency energy and analyzes the frequency shift (Doppler effect) of the

echoes reflected from moving targets. It enables the detection and tracking of moving targets while mitigating the effects of clutter and interference.

3. **Synthetic Aperture Radar:** SAR uses a combination of radar pulses and the movement of the radar platform to create high-resolution images of the Earth's surface. By processing the echoes received at different positions, SAR can generate detailed images of terrain, vegetation, and man-made structures.
4. **Phased Array Radar:** Phased array radar employs an array of antenna elements that can steer and shape the radar beam electronically. It provides rapid scanning, high flexibility, and improved target tracking capabilities by electronically adjusting the beam direction and shape without mechanical movement.
5. **Frequency Modulated Continuous Wave (FMCW) Radar:** FMCW radar emits a continuous signal with a modulated frequency. By measuring the frequency difference between the transmitted and received signals, FMCW radar can determine the range and velocity of targets. It is often used in applications such as automotive radar and short-range radar systems.

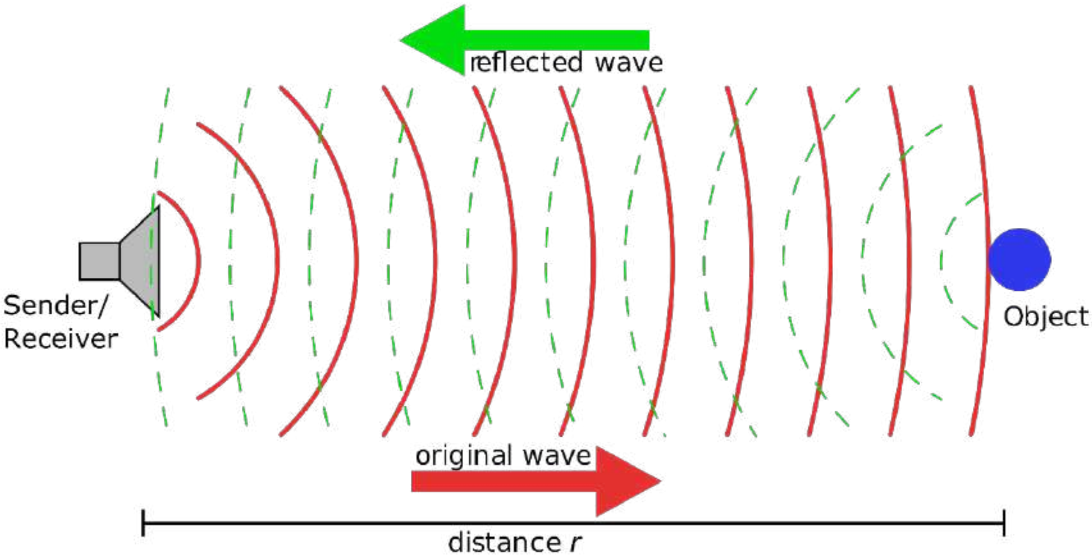


Figure 2-1: Fundamental Principle of Echo Detection in Radar [2]

Perhaps the most fundamental equation regarding radar is The Radar Equation, it is used to calculate the estimated maximum range. The purpose of this equation is to calculate the power and gain required to achieve the targeted range.

$$R_{max} = \sqrt{\frac{P_S G^2 \gamma^2 \sigma}{P_{e_{min}} (4\pi)^3 L_{ges}}} \qquad \text{(Eq 2.1)}$$

P_s = *transmitted power [W]*
G = *antenna gain*
Υ=*wavelength [m]*
σ = *radar cross section [m²]*
P_{Emin} = *smallest received power that can be detected by the radar [W]*
L_{ges} = *loss factor*

Another important aspect of the radar design is determining the correct PRF, as PRF is detrimental in dictating the maximum unambiguous range of the radar.

$$R_{max} = \frac{c_o}{2PRF} \qquad \text{(Eq 2.2)}$$

$$PRI = \frac{1}{PRF} \qquad \text{(Eq 2.3)}$$

Where c_o is the speed of light. The PRF is also detrimental in estimating doppler shift. Maximum unambiguous range increases as the PRF decreases but PRF has an opposite relationship with doppler. Due to this paradox most radars have a variable PRF [3].

2.1.2 Key Signal Processing Blocks

The key signal processing blocks for Radar have been highlighted below.

2.1.2.1 Intra Pulse Modulation

Intra-pulse modulation, also known as pulse-to-pulse modulation, is a technique used in radar systems to embed additional information within individual radar pulses. Unlike traditional pulse modulation where information is encoded between different pulses, intra-pulse modulation manipulates the properties of a single pulse to convey additional information. Intra-pulse modulation typically involves modifying the pulse's characteristics, such as its phase, frequency, amplitude, or time duration, in a controlled and deliberate manner [4]. These modifications introduce variations within the pulse waveform, allowing for the encoding of supplementary data or features. The primary objective of intra-pulse modulation is to improve radar system performance by achieving better target detection, identification, and discrimination capabilities. By embedding additional information within a pulse, radar systems can enhance their ability to differentiate between different targets or clutter sources, improve range resolution, and extract more detailed target signatures. Some common techniques used in intra-pulse modulation include:

Frequency Modulation (FM): Modulating the frequency of the radar pulse within the pulse duration, enabling the extraction of target Doppler frequency information, for example **LFM.**

Phase Modulation (PM): Introducing phase variations within the pulse to encode supplementary information, allowing for improved target identification and discrimination, for example **Barker Encoding.**

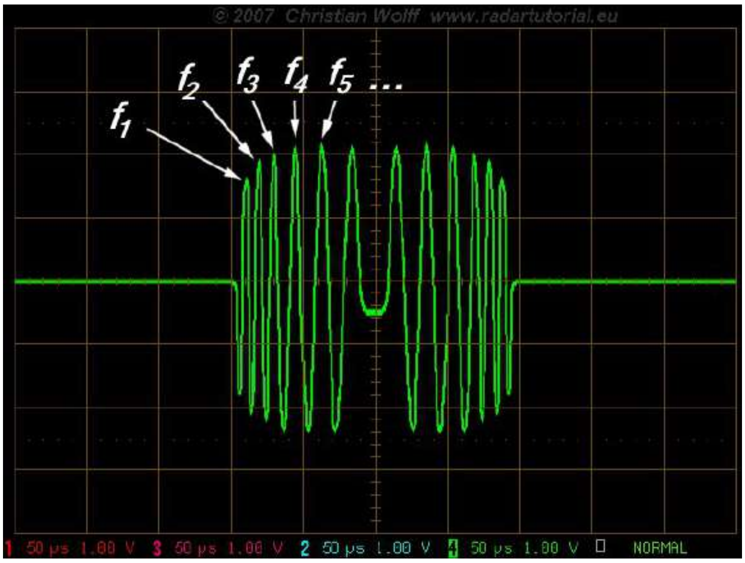


Figure 2-2: LFM signal [5]

2.1.2.3 Pulse Integration

Pulse integration refers to the process of combining multiple pulses of a radar or sonar system to improve target detection and increase signal-to-noise ratio (SNR). This technique is used to enhance the system's performance by accumulating the energy from multiple pulse repetitions.

In **coherent pulse integration**, consecutive pulses are combined in a phase-coherent manner. This means that the phase relationship between the pulses is preserved during integration. The received echoes from each pulse are added together, taking into account their respective phases, before further processing. Coherent integration can significantly improve the detection of weak targets by reinforcing the echoes that are in-phase across multiple pulses, effectively increasing the overall SNR [6].

For example, when a radar or sonar system receives echoes from a target, the coherent pulse integration aligns the received signals in a way that the target's echoes from different pulses add constructively, while noise tends to average out due to its random phase relationship. This results in a stronger and clearer target signal.

In **non-coherent pulse integration**, consecutive pulses are combined without preserving their phase relationships. The received echoes from each pulse are first squared (or the amplitude is squared) before being added together. Squaring the amplitudes removes the phase information and only retains the magnitude of the signal. Non-coherent integration is simpler to implement compared to coherent integration, but it is less effective in increasing SNR for weak targets. This is because non-coherent integration adds up the power of the target and noise alike, leading to less improvement in the SNR compared to coherent integration [6].

Non-coherent pulse integration is often used in scenarios where phase coherence cannot be easily maintained, such as when dealing with moving targets or in situations with rapidly varying interference.

In summary, pulse integration, whether coherent or non-coherent, is a valuable technique to improve target detection in radar and sonar systems. Coherent integration preserves the phase relationship for enhanced SNR, while non-coherent integration is simpler but provides less SNR improvement. The choice between the two methods depends on the specific requirements of the application and the target characteristics.

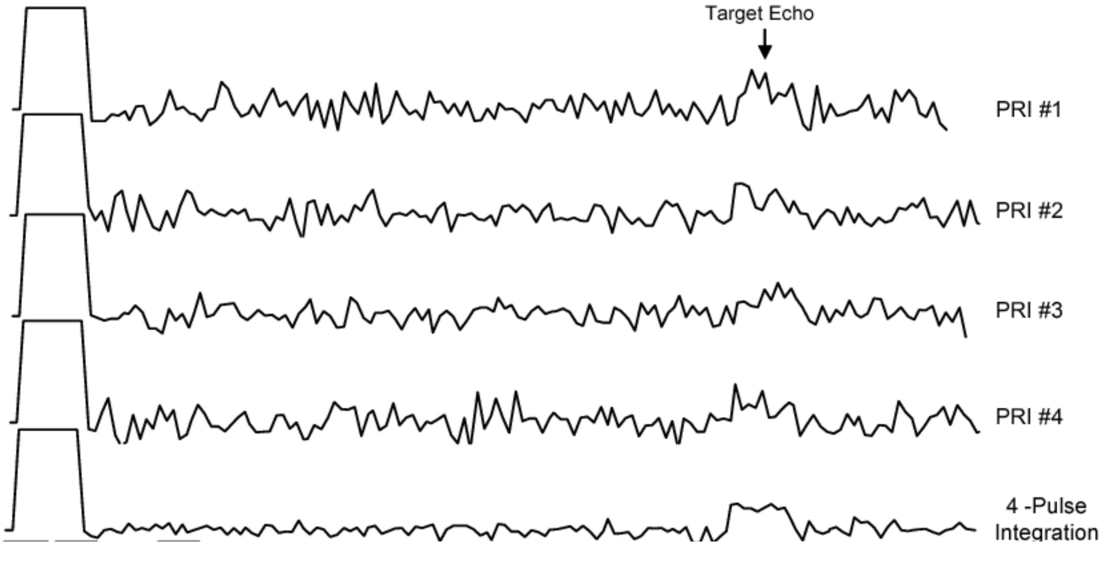


Figure 2-3: Pulse Integration [6]

2.1.2.4 Matched Filtering

Matched filtering is a signal processing technique used to enhance the detection of a specific signal in the presence of noise. It is commonly employed in radar, sonar, and communication systems. When a signal is transmitted and received, it is often corrupted by noise or interference. The goal of matched filtering is to maximize the signal-to-noise ratio and improve the ability to detect the desired signal in noisy conditions. The process involves correlating the received signal with a template waveform known as the "matched filter." This matched filter is designed to be an exact replica of the expected signal that is to be detected. In other words, it is shaped to match the characteristics of the desired signal.

By convolving the received signal with the time-reversed matched filter, the received signal is effectively aligned with the template. The output of this convolution is then integrated over a specific time period, effectively summing up the correlated values. If the received signal contains the desired signal, the correlation process will maximize the output, making the target signal stand out more clearly from the background noise [7]. On the other hand, noise or other unwanted signals that do not match the template will result in low correlation output. Matched filtering is especially useful when the transmitted signal and the expected signal are known and deterministic. It significantly improves the SNR and increases the probability of successfully detecting weak signals buried in noise.

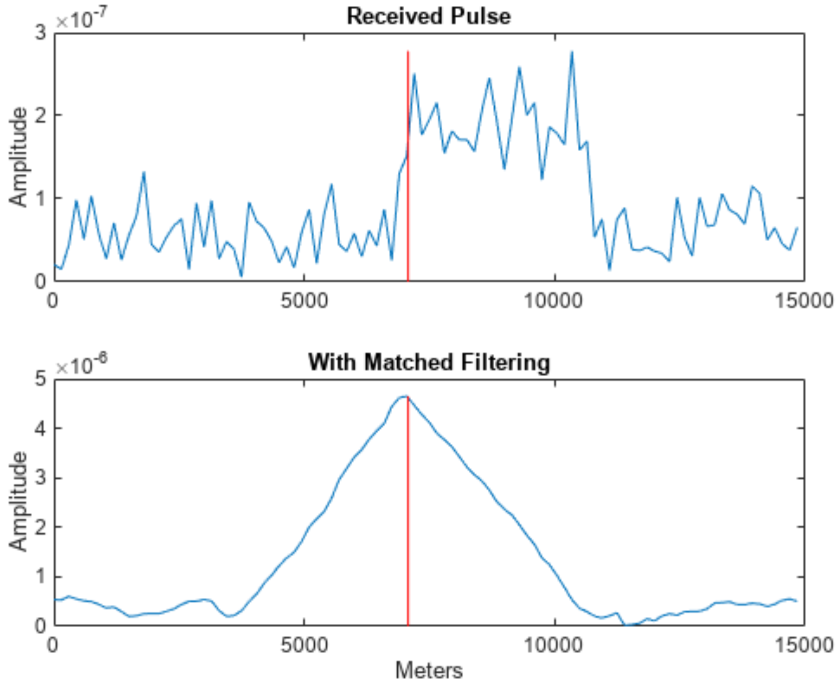


Figure 2-4: Matched Filtering

2.1.2.5 Pulse Compression

Pulse compression is a technique used in radar systems to enhance range resolution while maintaining high transmitted power. It allows for improved target detection and identification by achieving finer range discrimination capabilities [8]. In traditional radar systems, a longer pulse duration is desirable for better range detection. However, longer pulses result in lower range resolution, making it difficult to differentiate between closely spaced targets. Pulse compression techniques overcome this limitation by compressing the transmitted pulse into a much shorter duration while maintaining the benefits of a longer pulse. The pulse compression process involves transmitting a longer duration signal, known as the "chirp" or "coded pulse," which is designed with specific modulation characteristics. This modulation is typically achieved by frequency or phase modulation within the pulse.

The transmitted signal is then correlated with a matched filter or a matched processing algorithm at the receiver to recover the original longer pulse. The correlation process enhances the power of the returned echoes from the targets, effectively compressing them in time [8]. This compression improves the range resolution, allowing for the detection and discrimination of targets that are closely spaced in range. Benefits of pulse compression in radar systems include:

1. **Improved Range Resolution:** Pulse compression enables finer range discrimination, allowing for the detection and identification of closely spaced targets that would otherwise merge into a single echo with a longer pulse.
2. **Increased Sensitivity:** By compressing the echo signals, pulse compression techniques enhance the received signal power, leading to improved detection sensitivity and the ability to detect weak or distant targets.
3. **Enhanced Target Identification:** The improved range resolution provided by pulse compression enables better target identification and discrimination, especially in scenarios with dense target environments or clutter.
4. **Interference and Clutter Rejection:** Pulse compression can help mitigate the effects of interference and clutter by suppressing signals that do not match the compression characteristics, enhancing target detection in challenging environments.

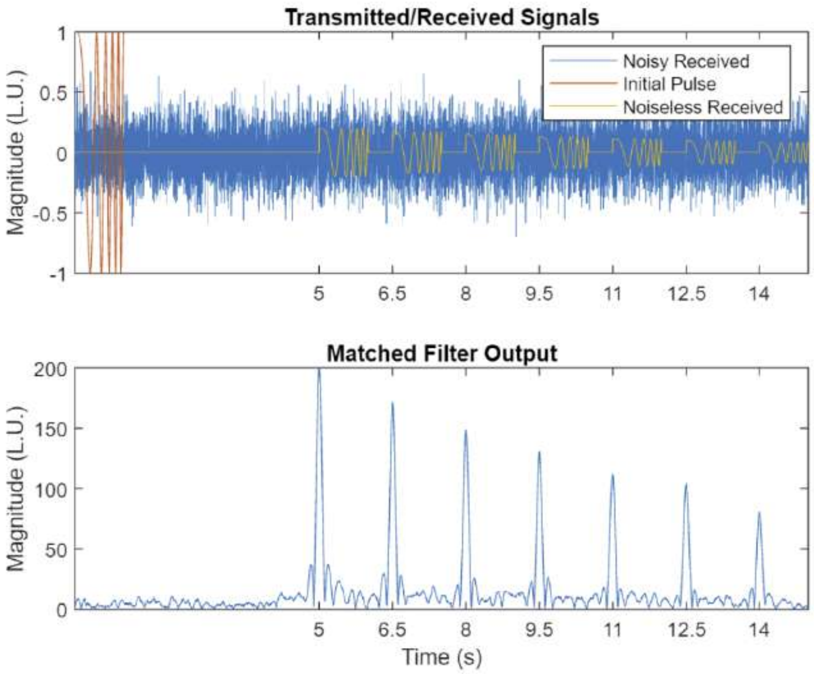


Figure 2-5: Matched Filtering with Pulse Compression

In figure 2-4, it is evident that matched filtering in case of an unmodulated pulse does not yield in good range resolutions since close by targets are difficult to segregate. But in figure 2-3, it can be seen how pulse compression improves the range resolution but giving a sharper peak at the target location.

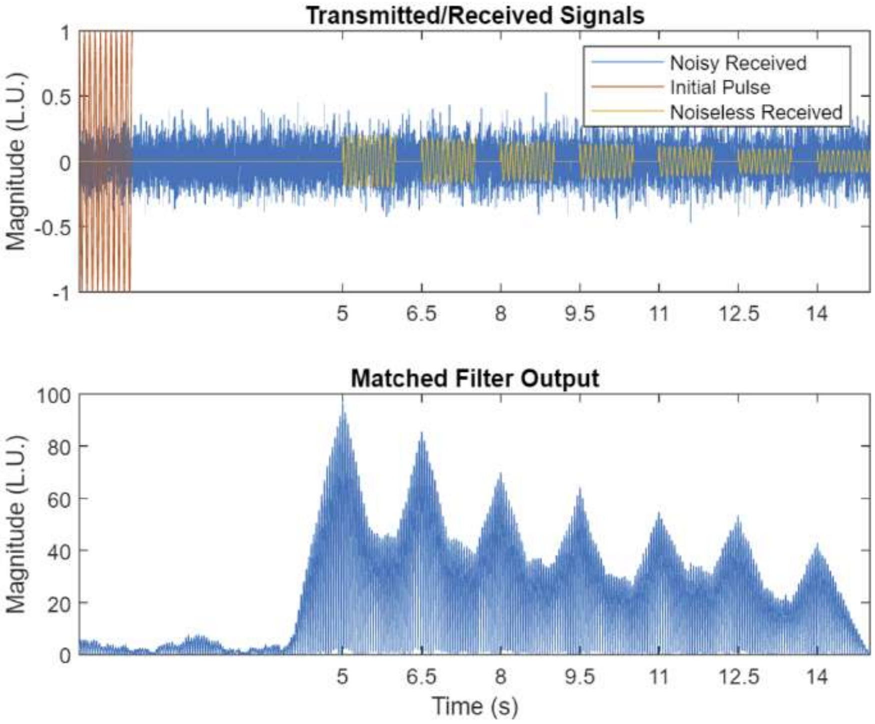


Figure 2-6: Matched Filtering Without Pulse Compression

Notice how the targets are easier to segregate in range when pulse compression is used, as pulse compression not only reduces the side lobes but also enhances detectability of the target in terms of maximum range and range resolution.

2.1.2.6 Sensitivity Time Control

STC is a technique used in radar systems to automatically adjust the receiver's sensitivity based on the target's range or distance. It is an essential feature in radar systems because it helps to optimize the detection and display of radar echoes in varying environmental conditions.

The primary purpose of STC is to compensate for the attenuation or weakening of radar echoes as they travel through space. As the radar signal propagates, it encounters various obstacles such as atmospheric conditions, precipitation, terrain, and clutter that can attenuate or reflect the signal. These factors can cause echoes from distant targets to be weaker compared to those from nearby targets.

By applying STC, the radar receiver's sensitivity is adjusted over time as a function of range. The sensitivity is usually increased for longer ranges where echoes are weaker and reduced for shorter ranges where echoes are stronger.

2.2 Amplitude Based DF

Amplitude-based direction finding (DF) is a passive technique that estimates the direction of a signal source based on the relative differences in signal strength received by multiple antennas or antenna elements. This brief introductory section provides an overview of Amplitude based DF, highlighting its key principles and applications.

2.2.1 Fundamental Principle

Amplitude-based direction finding is a technique that estimates the direction of a signal source by analyzing the relative signal strengths received at different antennas or antenna elements. Amplitude-based DF relies on the concept that the amplitude of a signal varies with the angle of arrival [9]. When a signal reaches multiple antennas or antenna elements, the differences in the received signal strengths can be used to estimate the direction from which the signal originates. Various amplitude-based DF techniques have been developed, including switched arrays, monopulse systems, and amplitude comparison methods [9]. These techniques employ different strategies for extracting directional information from the received signals. Most Amplitude based DF techniques are:

1. **Switched Array Direction Finding:** This technique involves sequentially switching the received signal from different antenna elements or subarrays to estimate the angle of arrival based on the relative amplitudes.
2. **Monopulse Direction Finding:** Monopulse DF utilizes multiple simultaneous beams with slightly different angles to accurately estimate the AOA. By comparing the relative signal strengths received in each beam, the direction of the signal source can be determined.
3. **Amplitude and Phase Comparison Direction Finding:** This technique combines amplitude and phase measurements to estimate the AOA. It utilizes both the amplitude and phase differences between the received signals to improve the accuracy of direction finding.
4. **Beamforming Direction Finding:** Beamforming techniques utilize arrays of antennas to steer and shape the received signal beam towards the desired direction. By adjusting the relative amplitudes of the signals received at each antenna element, the direction of the signal source can be estimated.

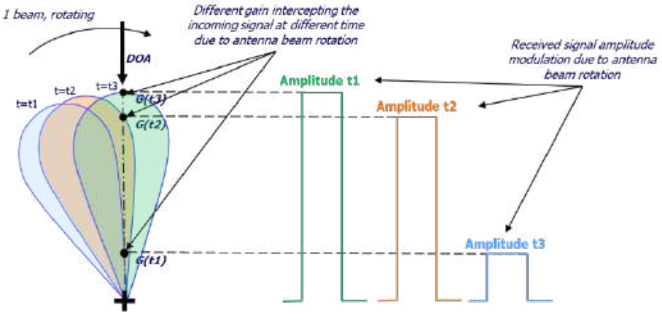


Figure 2-7: Fundamental Principle of Amplitude Based DF [10]

2.2.2 Key Signal Processing Blocks

The following section outlines the key signal processing blocks in amplitude-based DF.

2.2.2.1 Fast Fourier Transform

It is a widely used mathematical algorithm that efficiently computes the Discrete Fourier Transform (DFT) of a discrete sequence of data points. The DFT is a transformation that converts a time-domain signal into its frequency-domain representation. The FFT algorithm exploits symmetries and redundancies in the DFT calculation, allowing for a significant reduction in computational complexity compared to the standard DFT computation [11]. This makes it practical to perform spectral analysis and frequency-domain processing of signals in real-time or near real-time applications. The basic principle of the FFT algorithm is to divide the input data sequence into smaller sub-sequences, recursively applying the DFT on these smaller segments, and then combining the results to obtain the final frequency-domain representation. By exploiting properties of complex exponentials and employing efficient indexing schemes, the FFT algorithm reduces the number of computations required from O(N^2) to O(N log N), where N is the length of the input data sequence.

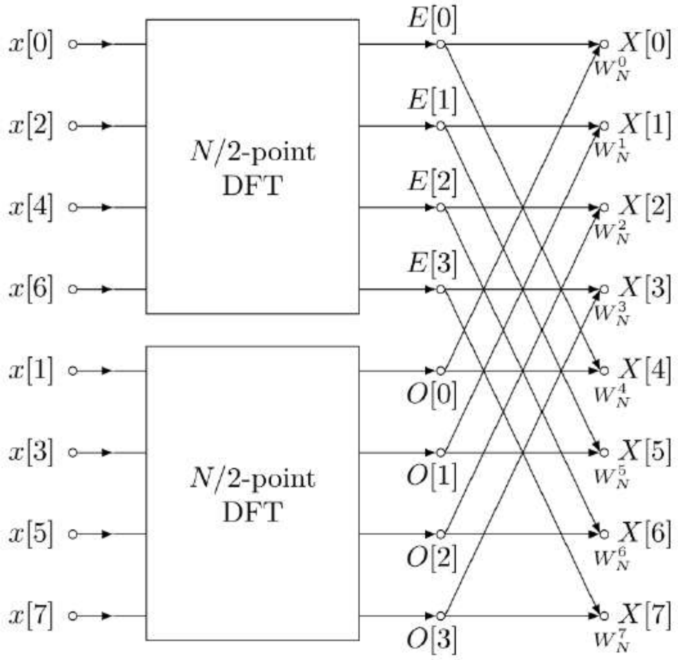


Figure 2-8: Flowchart of FFT Algorithm [11]

2.2.2.2 Regression

Regression is a statistical technique used to model the relationship between a dependent variable and one or more independent variables. It aims to identify and quantify the associations between the independent variables and the dependent variable, allowing for prediction or estimation of the dependent variable based on the independent variables. In regression analysis, the dependent variable is typically a continuous or numeric variable, while the independent variables can be continuous, categorical, or a combination of both. The objective is to find the best-fitting regression model that describes the relationship between the variables. The regression model estimates the impact or effect of the independent variables on the dependent variable by determining the regression coefficients or parameters [12].

These coefficients indicate the magnitude and direction of the relationship between the variables. The regression model can be used to make predictions, understand the significance of the independent variables, and assess the overall goodness-of-fit of the model.

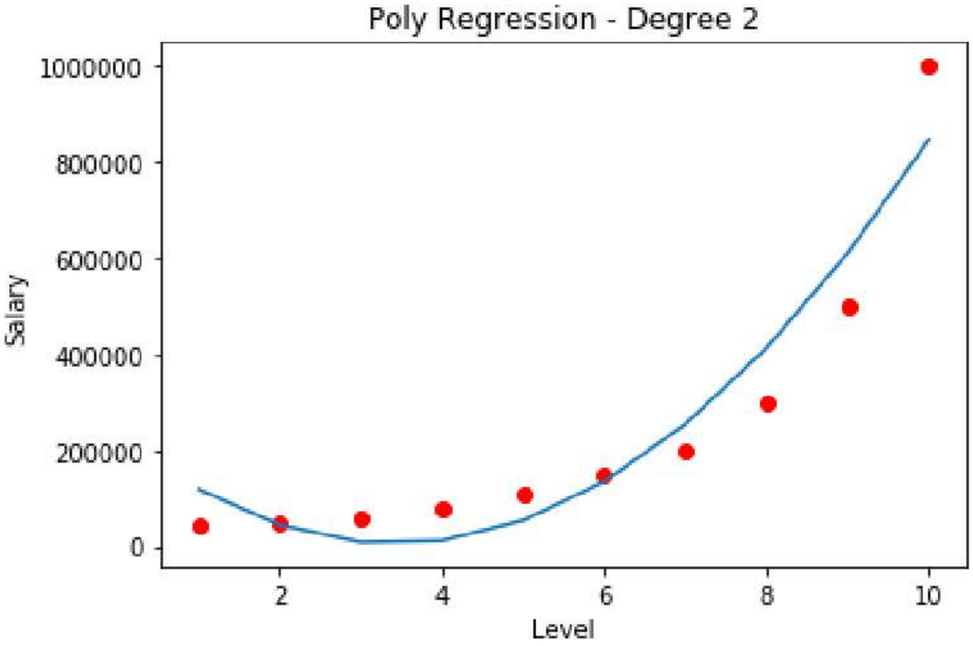


Figure 2-7: An Example of Polynomial Regression [12]

2.3 Related Projects

A lot of literature is present on active and passive systems, but the key papers used to develop the basic blocks for both the systems are given in the following sections.

2.3.1 Amplitude and Phase Direction Finding

This paper by D. J. Torrieri explores the principles and methods of amplitude and phase-based direction finding [13].

Table 2-1: DF Paper Details

Title	Statistical Theory of Passive Location Systems
Author	D. J. Torrieri
Published	IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-20, No. 2, March 1984

It presents an in-depth analysis of amplitude DF techniques, including switched arrays, monopulse systems, and amplitude comparison methods. The authors discuss the underlying theory, algorithms, and performance characteristics of these techniques, making it a valuable resource for researchers and practitioners working in the field of direction finding.

2.3.2 Radar Signals: An Overview and Perspective

In this seminal paper, Skolnik provides a comprehensive overview and perspective on history of radar [1].

Table 2-2: Radar Paper Details

Title	Fifty years of radar
Author	M. I. Skolnik
Published	Proceedings of the IEEE*,* vol. 73, no. 2, Feb. 1985

The paper covers the principles and applications of pulse compression, including matched filter processing, range resolution enhancement, ambiguity function analysis, and waveform design. Skolnik discusses the advantages, limitations, and trade-offs associated with different pulse compression techniques and provides insights into their practical implementation. This paper has significantly influenced radar signal processing research and continues to be a valuable resource for researchers, engineers, and practitioners working in radar systems, target detection, and range resolution enhancement through pulse compression.

2.4 Limitations and Bottlenecks of the Existing Work

The existing work on active and passive detection techniques, while valuable and insightful, has certain limitations due to the lack of integration and comparative analysis of these approaches. The separate treatment of active and passive detection techniques has led to an incomplete understanding of their combined potential. Without comparing and analyzing them together, researchers may not have a comprehensive understanding of their synergies, limitations, and potential trade-offs. Active and passive detection techniques possess complementary characteristics that, when combined, can enhance overall detection capabilities. However, the lack of integration in existing work means that potential synergistic benefits have not been fully explored or leveraged.

2.5 Problem Statement

Passive and Active systems are both operational, independently, in different applications, but they are not being used together in a multirole hybrid architecture. The main goal of this project is to gain a deeper understanding into active and passive systems how they can be combined to make a multirole hybrid architecture which has the advantages of both and disadvantages of none.

2.6 Summary

The chapter discussed the key fundamental principles and algorithms related to active and passive systems. The chapter also went over two important reference papers related to these technologies.

Chapter 3

PROJECT DESIGN AND IMPLEMENTATION

In this chapter the hardware and software design of the Active and Passive system is proposed. The implementation of key signal processing blocks of both are systems are also discussed.

3.1 Proposed Design Methodology

The proposed design methodology is given in figure 3-1, the systems consist of detection techniques, active and passive, both. The main elements for both the architecture is the hardware and RF front-end design and the signal processing chain. The signal processing chain of both the architectures has been written from scratch, while the front-end design uses COTS products.

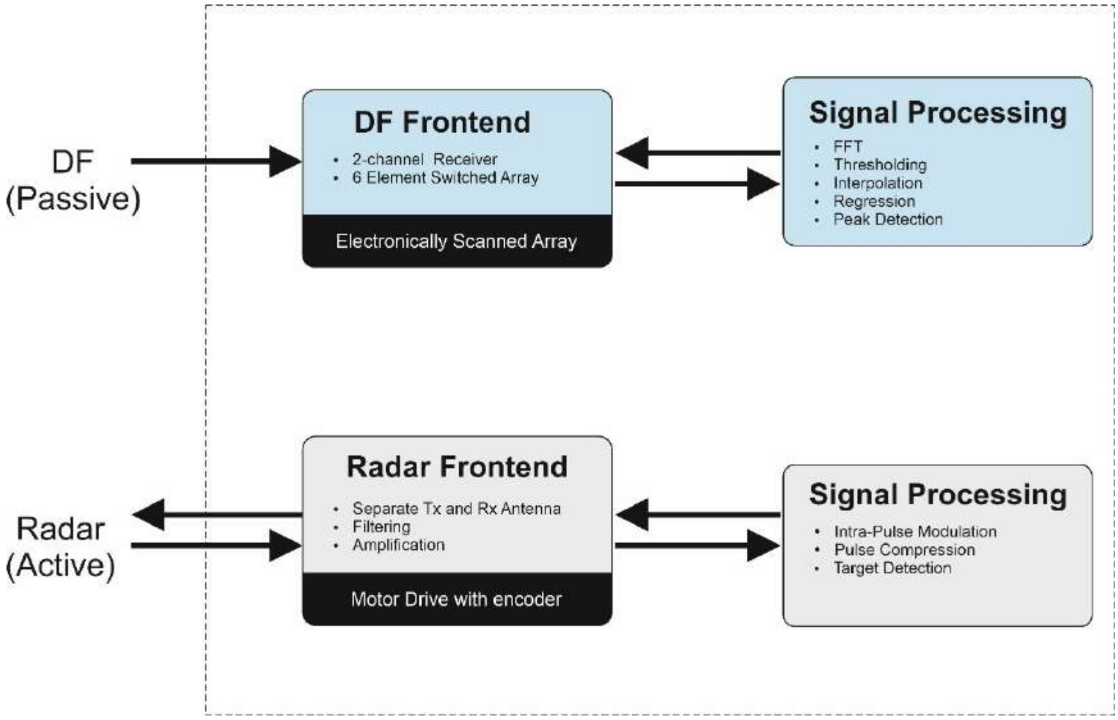


Figure 3-1: Proposed Design for The System

3.2 Design and Implementation of the Project Hardware and Software

The details of the hardware and software architecture for both the systems, passive and active, are given in the following sections.

3.2.1 Passive detection (DF)

The proposed hardware and software architecture is given in figure 3-2.

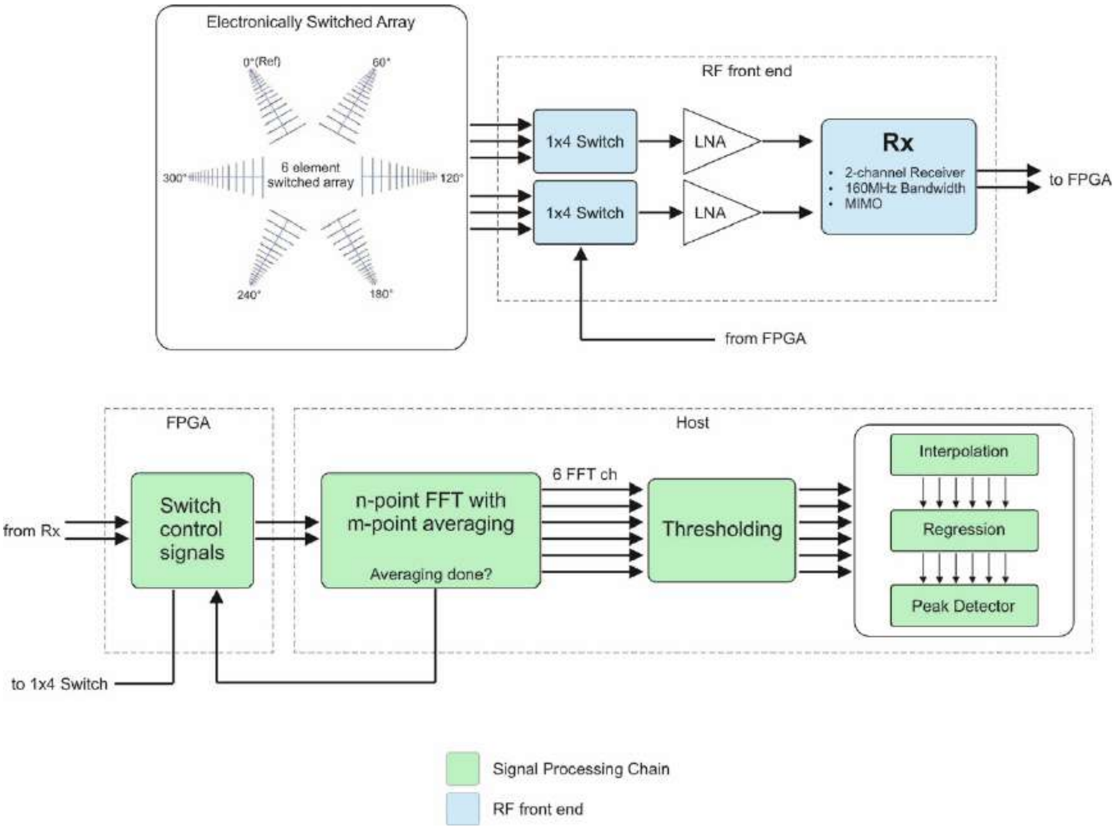


Figure 3-2: Proposed Design For DF

A six-element switched array has been incorporated in this project, since only 2 RF channels are available, a 1x4 RF switch is being used to switch between the elements. It takes 3 switch states to acquire data from all the elements. The switch is being controlled by the FPGA. After the switch, an LNA is added so that weak signals can be detected by the receiver, whenever using an amplifier, it is imperative to use a limiter before the amplifier to maximize its dynamic range, otherwise the resultant signal can be clipped if it is not scaled properly. At the last stage of the RF front-end, the signal is down converted, then the signal is digitized by an ADC and then enters the FPGA.

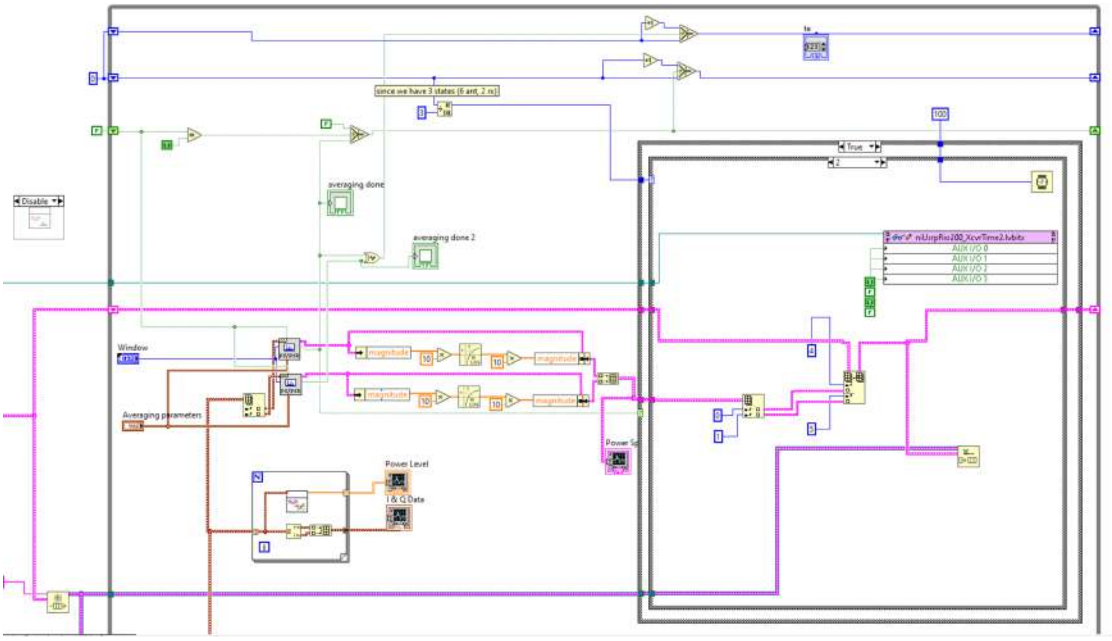


Figure 3-3: FFT Averaging and Switch States Implementation in LabVIEW

The signal processing chain begins as soon as the signal reaches the FPGA. The FPGA is used to coherently acquire the signal in terms of phase and amplitude, due to the determinism of the FPGAs inherent architecture, it is suitable to use it as digital acquisition and signal conditioning block.

The clock of the ADC and FPGA is synchronized, which ensures signal coherence and integrity. The FPGA acquires the signal and streams it to the host via a FIFO buffer, ensuring that no sample is missed. After which the FFT of the signal is calculated. The amplitude of the target signal can vary significantly with time due to a magnitude of reasons, hence, it is imperative to take the averages of the FFT spectrum so that the amplitude of the frequency bins is stable. Averaging can lead to inaccurate results of angle if the target is in motion but can lead to better results in case of pulsed or frequency hopping signals. After taking the FFT and averaging it, the host signals to the FPGA that the averaging is complete, and it can switch to the next set of elements. The FPGA then switches to the next channel and the process is repeated until the averaged spectrum data of all 6 elements is available.

The switching time is 100ms because the switching signal is being sent from the host, the switching time can be as low as 320ns, which is the switching time of the RF switch if this block is implemented on FPGA. There are a total of 3 switching states, in the first state data of element 0 & 60 are collected, then 120 & 180, and finally 240 & 300. Since there are only 6 elements, the resolution of signal power with respect to angle is limited in terms of resolution, so it is important to interpolate the data, after which regression is calculated, and the best possible function is fit to the data (amplitude with response to angle).

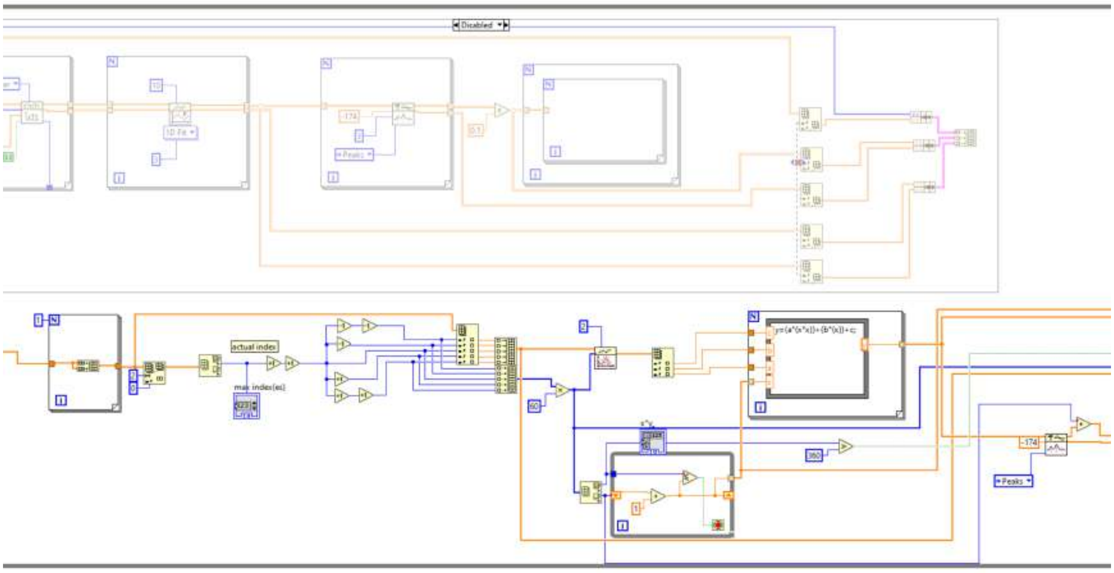


Figure 3-4: Regression and Peak Detection Implemented In Labview

A second order polynomial is being used to fit the data, which inherently limits the number of targets that can be found in a single frequency bin to 1. The most suited function for regression in this application would be B-Spline since the number of maximas and minimas can be adjusted dynamically. Although B-Splines have the tendency to overfit, but by using a fixed order polynomial, the function will force *Order-1* peaks and valleys which will lead to incorrect results, since the number of maximas depends entirely on the number of arriving signals and their directions, which cannot be known.

The maxima of the regressed dataset is found by taking the 1st and 2nd order derivative of the data. The index of the zero values of the 1st order derivative indicates the AOA of the target. Lastly, the statistical parameters of the AOA are measured, such as mean, variance, standard deviation, and the mean of the angle is then displayed in the GUI.

3.2.2 Active Detection (Radar)

For the radar there are 2 separate RF chains, the receive and transmit chain, both in terms of RF front-end and signal processing. In the transmission chain, an array of LPDA was used for three key reasons. Firstly, to increase the gain. Secondly, to reduce beamwidth. Lastly, the power handling of a single antenna is only 5W (as tested), so it is easy to distribute power into an array of antennas rather than source a single high-power antenna. The transmit signal is amplified using a power amplifier, then split in 4 channels by a 1x4 RF splitter, which is eventually fed to an array of four LPDAs. For a receive chain, a narrow band parabolic antenna, commonly referred to as a dish antenna, is used for two key reasons. Firstly, parabolic antennas provide very high gain at the frequency they are designed for. Secondly, narrow band antennas also act as narrow band filters. The output of the parabolic antennas is then fed to an LNA and then to the receiver.

All the antennas are mounted on a rotatory platform which can move in azimuth and elevation, the position of rotating platform is being calculated using the built-in encoders of both the, azimuth and elevation, motors. A compass is also integrated to generate a north alignment pulse, so that the target geolocation can be calibrated with reference to north.

The most fundamental part of the radars signal processing chain is that the receiver and transmitter need to be synchronized and coherent with respect to each other, as the radar needs to receive and transmit simultaneously and coherently, to ensure correct operation. After the coherent Rx data is sent to the host, the Rx data contains the information of multiple coherent PRIs, data of every single PRI needs to be extracted and stored. The PRIs are extracted using an analog edge detection block, the transmit signal triggers the PRI acquisition, since the PRI size is known, a trigger is only required to start the acquisition, and not stop it.

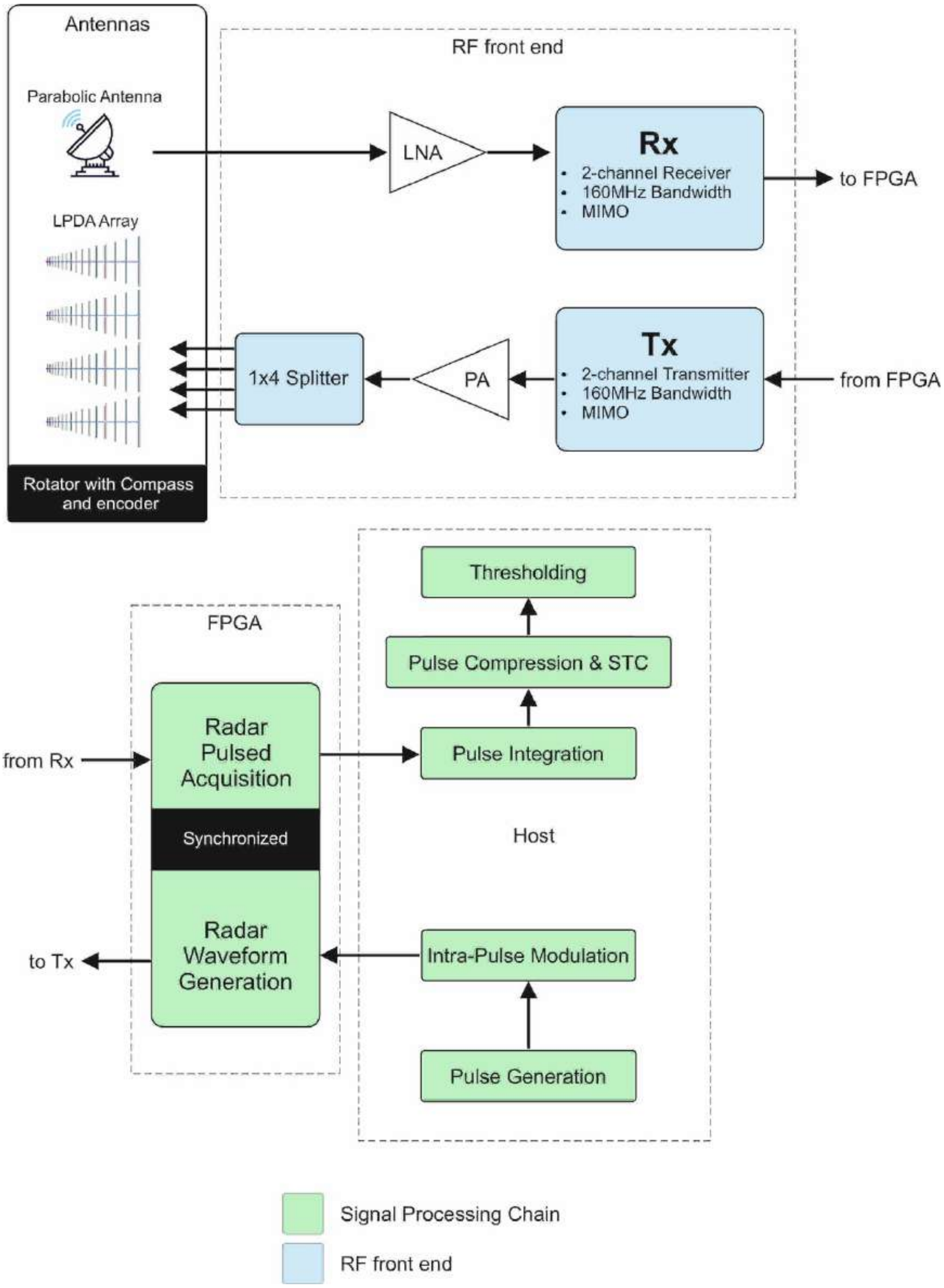
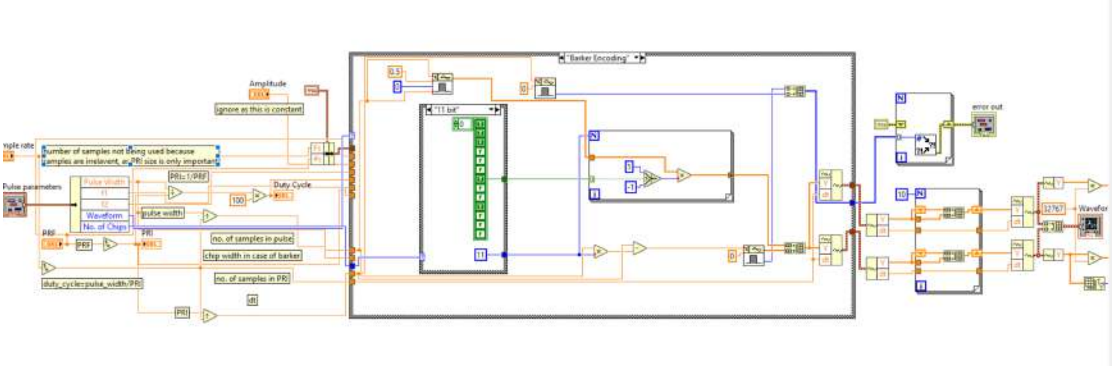


Figure 3-5: Proposed Design for Radar

After data of *N* PRIs is acquired, coherent pulse integration is performed to enhance the SNR, as the received echoes are very weak in terms of power. After pulse integration, a matched filter is applied to the modulated transmission pulse. Matched filtering is a very important signal processing block in Radar signal processing because it only uses the template waveform itself to improve the SNR. Since the transmission pulse is modulated this is also known as pulse compression.

Pulse compression increases the range resolution and also increases the probability of detection. After pulse compression, it is observed that the echoes coming from the targets in the starting range bins have more power, and the echoes coming from the targets in further range bins have less power (closer targets will always have a stronger echo due to less free space loss), in order to mitigate this issue sensitivity time control is implemented.

Sensitivity time controls attenuate the power of the signal in the starting range bins, and amplifies the power exponentially as the range bin starts to get further (in terms of distance from the radar receiver)



number of samples not being used because samples are irrelevant, as PRI size is only important

Figure 3-6: Waveform Generation Block Implemented in LabVIEW For All Barker Sequences

The last step involves thresholding. A threshold can be set manually or CFAR thresholding can be used as an adaptive thresholding technique. Any value in the matched filter output which crosses the threshold is considered a valid target and is mapped as a valid target in the GUI. Clutter rejection is also a very important part of segregating valid targets from clutter by using doppler processing but that has not been implemented in the signal processing chain in this version.

As for the Tx signal processing chain, a pulse is generated based on 3 parameters. Pulse width, modulation type, and PRF. There are only 3 modulation options in this system, which are the following:

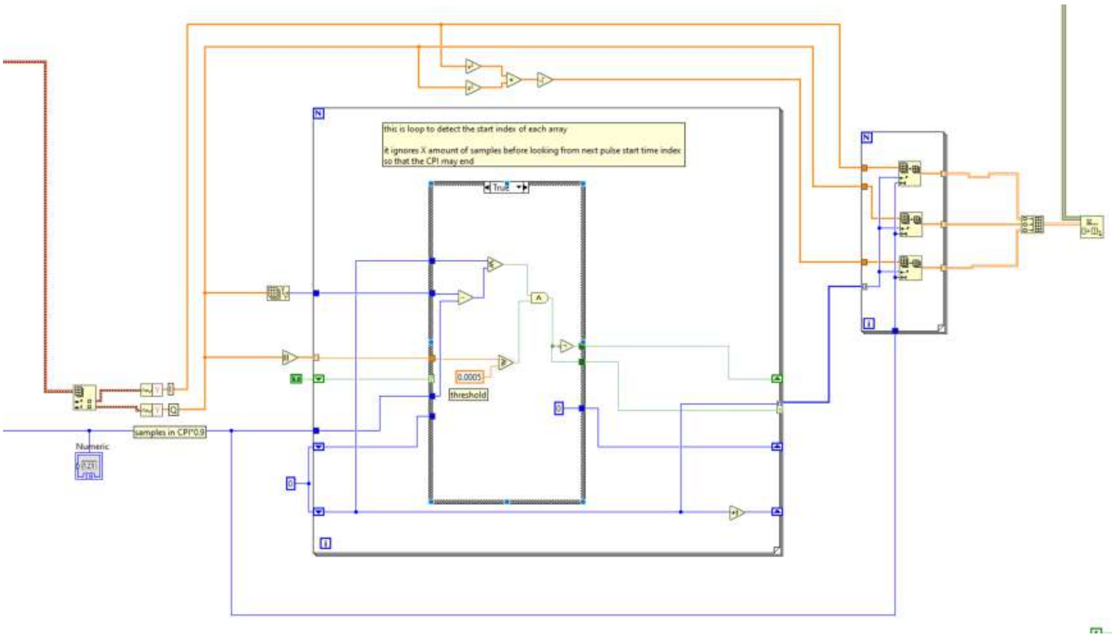
1. **No modulation:** Generates a standard pulse with a specific pulse width and PRF.
2. **Barker encoding:** Generates a barker sequence with phase modulation. For barker encoding, pulse width corresponds to chip width, and all known barker codes have been implemented. Barker codes are used because of their ideal autocorrelation properties. User needs to specify the length of barker encoding.

Table 3-1: Barker Encoding Lengths

Length	**Codes(phase)**
2	+−
3	++−
4	++−+
5	+++−+
7	+++−−+−
11	+++−−−+−−+−
13	+++++−−++−+−+

3. **LFM:** LFM generates a signal with initial frequency and final frequency, which needs to be specified by the user.

After the Tx signal is generated, it is fed to the FPGA through a FIFO buffer ensuring that no sample is missed. The signal is also fed back into the signal processing chain as it is utilized during matched filtering. The Tx chain needs to be coherent with the Rx chain, as timing is vital in a radar. The receiver is ‘blinded’ when the radar is transmitting, as the receiver is saturated by the transmitting signal and is unable to detect the Rx signal. This phenomenon is known as the blind range of the radar. The pulse width not only dictates range resolution, but also dictates the blind range.


this is loop to detect the start index of each array

it ignores X amount of samples before looking from next pulse start time index so that the CPI may end

Figure 3-7: PRI Extraction Block Implemented In LabVIEW

As the pulse width gets narrower, the DAC faces trouble generating the pulse due to its limited slew rate, which is evident in the form of transients and overshoot. These phenomena affected the performance of the system below pulse widths of hundred nano seconds.

3.2 Details of Simulations / Mathematical Modeling

The antennas were simulated before testing, to evaluate the performance of the antennas at the desired frequencies. The results have been displayed in the following figures.

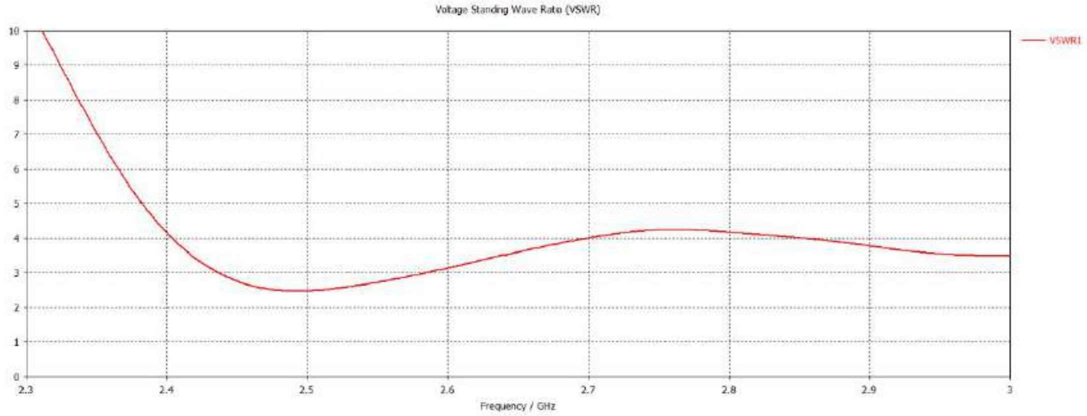


Figure 3-8: VSWR Of Parabolic Antenna (Radar Rx)

The gain and beam pattern of the receiving antenna of the radar were simulated, and the results are given in the figures below. It is to be noted that the dish performs optimally for the desired frequency of 2.5GHz.

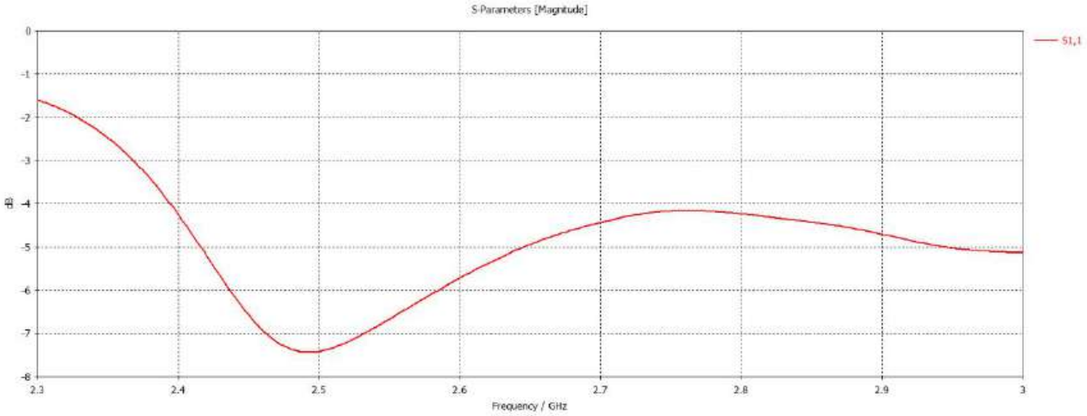


Figure 3-9:S11 Of Parabolic Antenna (Radar Rx)

Although the beamwidth of the Parabolic antenna in the simulation was not correct since parabolic antennas have narrow beam widths. This phenomenon is being investigated. The 3dB beamwidth of the antenna, after testing, was estimated to be 5 degrees.

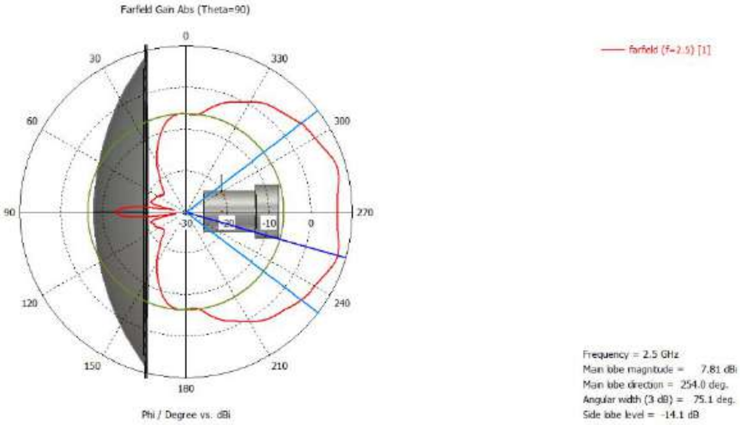


Figure 3-10:Beam Pattern And Gain Of Parabolic Antenna (Radar Rx)

The parameters of the reception LPDA antenna being used for DF were also simulated.

Figure 3-11: Gain of Rx LPDA DF

The results of the simulation signify a high gain for the entire band (>7dBi).

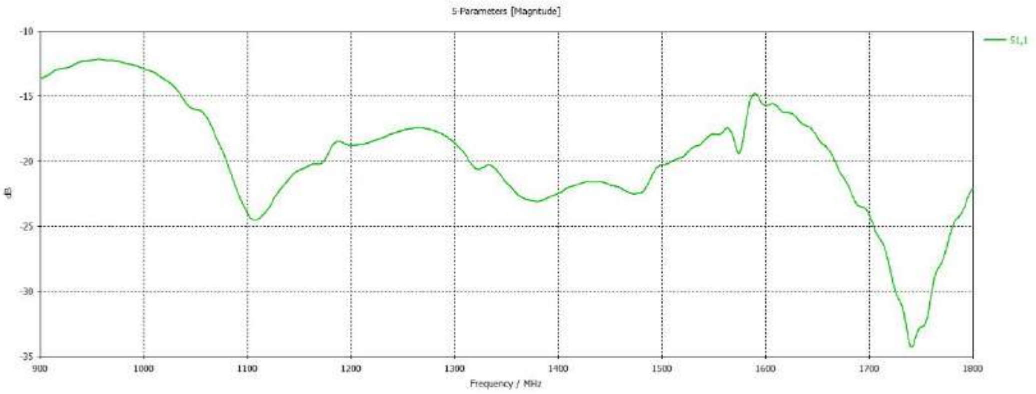


Figure 3-12: S11 of Rx LPDA DF

The VSWR of the LPDA is below 2 for the entire band and is below 1.5 for most of the band, which signifies it performs well for the designated band.

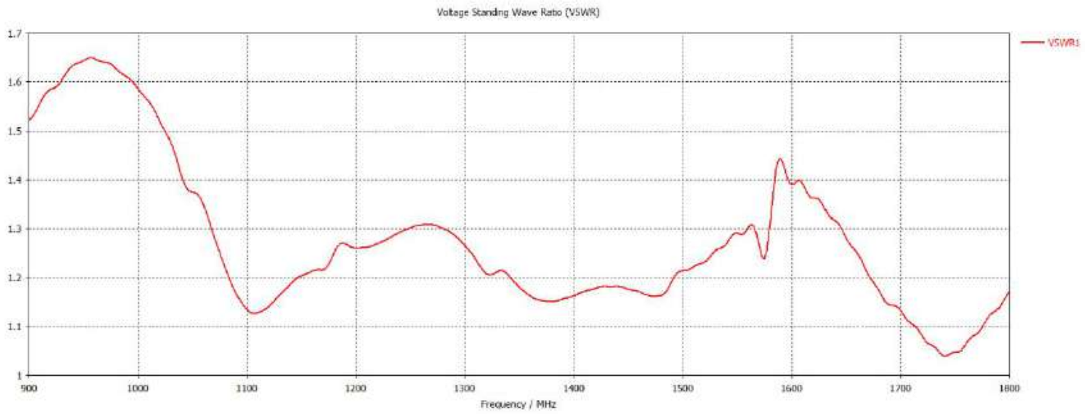


Figure 3-13: VSWR of Rx LPDA DF

The radiation pattern of the LPDA shows that it has a 3 dB beam width of 60 degrees.

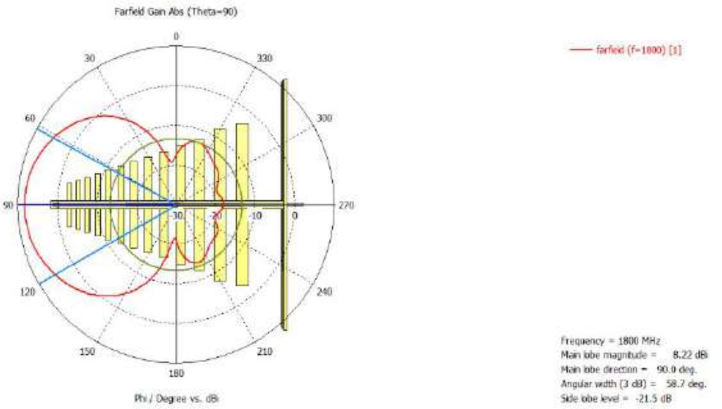
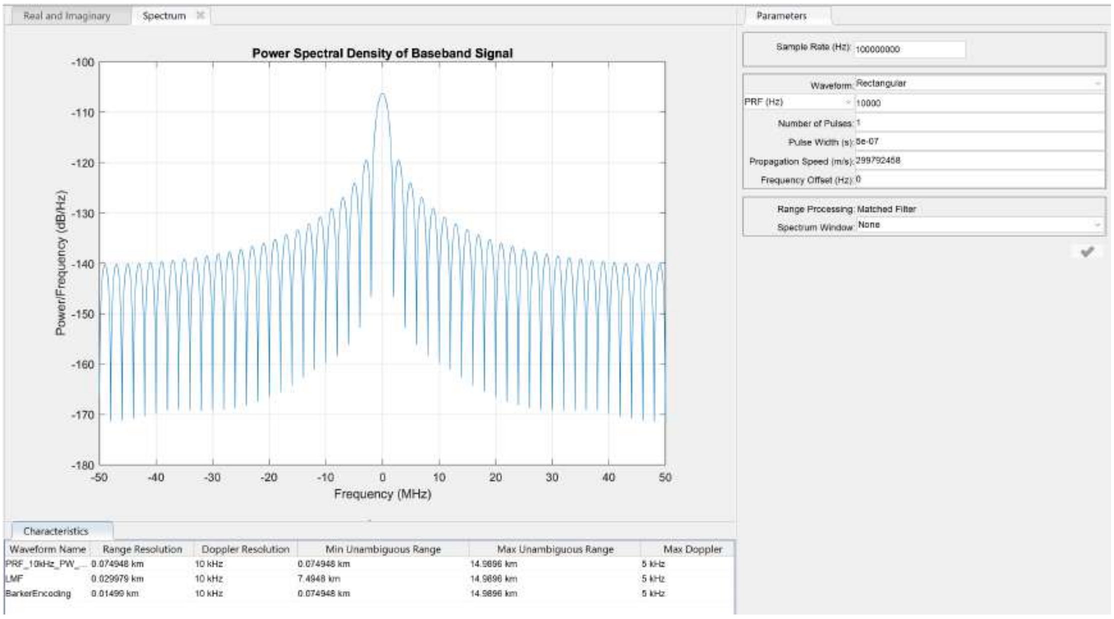


Figure 3-14: Beam pattern of Rx LPDA DF

The waveform design for the radar was first simulated in MATLAB to mitigate any unexpected results, all 3 desired waveforms were tested using the Pulse Analyzer tool. The parameters of the modulation can be seen in the figures below.



Sample Rate (Hz): 100000000

Waveform: Rectangular

PRF (Hz): 10000

Number of Pulses: 1

Pulse Width (s): 5e-07

Propagation Speed (m/s): 299792458

Frequency Offset (Hz): 0

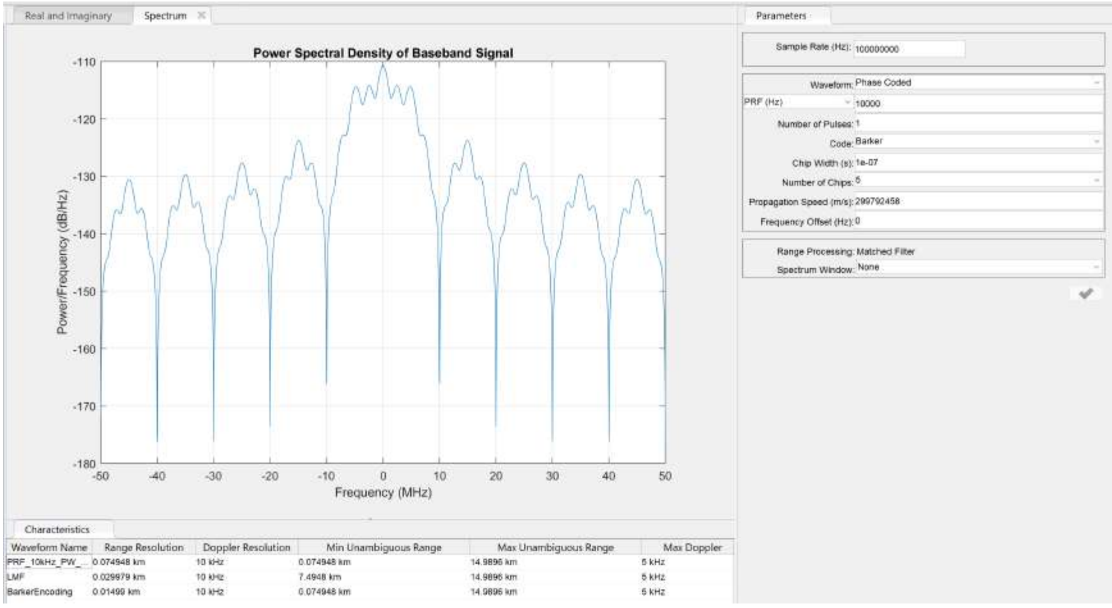
Range Processing: Matched Filter

Spectrum Window: None

Waveform Name	Range Resolution	Doppler Resolution	Min Unambiguous Range	Max Unambiguous Range	Max Doppler
PRF_10kHz_PW_...	0.074948 km	10 kHz	0.074948 km	14.9896 km	5 kHz
LMF	0.029979 km	10 kHz	7.4948 km	14.9896 km	5 kHz
BarkerEncoding	0.01499 km	10 kHz	0.074948 km	14.9896 km	5 kHz

Figure 3-15: No Modulation Simulation

All three of these waveforms have been implemented in the software implementation with variable parameters (user can set the parameters as desired).

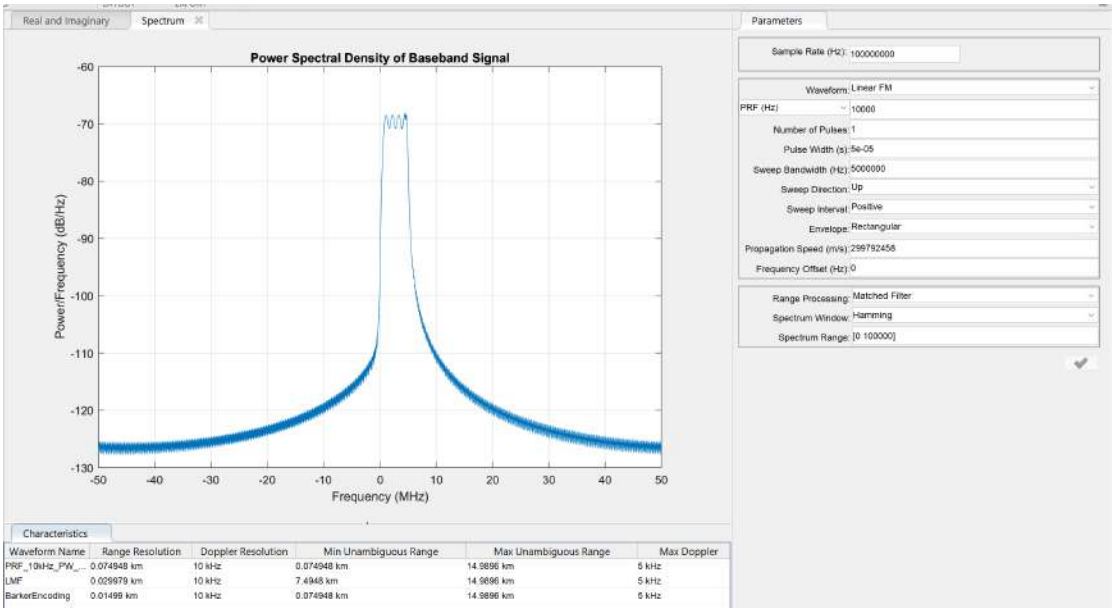


Sample Rate (Hz): 100000000
Waveform: Phase Coded
PRF (Hz) 10000
Number of Pulses: 1
Code: Barker
Chip Width (s): 1e-07
Number of Chips: 5
Propagation Speed (m/s): 299792458
Frequency Offset (Hz): 0
Range Processing: Matched Filter
Spectrum Window: None

Waveform Name	Range Resolution	Doppler Resolution	Min Unambiguous Range	Max Unambiguous Range	Max Doppler
PRF_10kHz_PW_...	0.074948 km	10 kHz	0.074948 km	14.9896 km	5 kHz
LMF	0.029979 km	10 kHz	7.4948 km	14.9896 km	5 kHz
BarkerEncoding	0.01499 km	10 kHz	0.074948 km	14.9896 km	5 kHz

Figure 3-16: Barker Simulation

The simulation results also indicate how these different waveforms have a unique effect on the range resolution and minimum unambiguous range. By modulating the pulse, it is possible to reduce the range resolution and minimum unambiguous range (also known as blind range), but it is not possible to change the maximum unambiguous range, which entirely depends on the PRF.



Sample Rate (Hz): 100000000
Waveform: Linear FM
PRF (Hz) 10000
Number of Pulses: 1
Pulse Width (s): 5e-05
Sweep Bandwidth (Hz): 5000000
Sweep Direction: Up
Sweep Interval: Positive
Envelope: Rectangular
Propagation Speed (m/s): 299792458
Frequency Offset (Hz): 0
Range Processing: Matched Filter
Spectrum Window: Hamming
Spectrum Range: [0 100000]

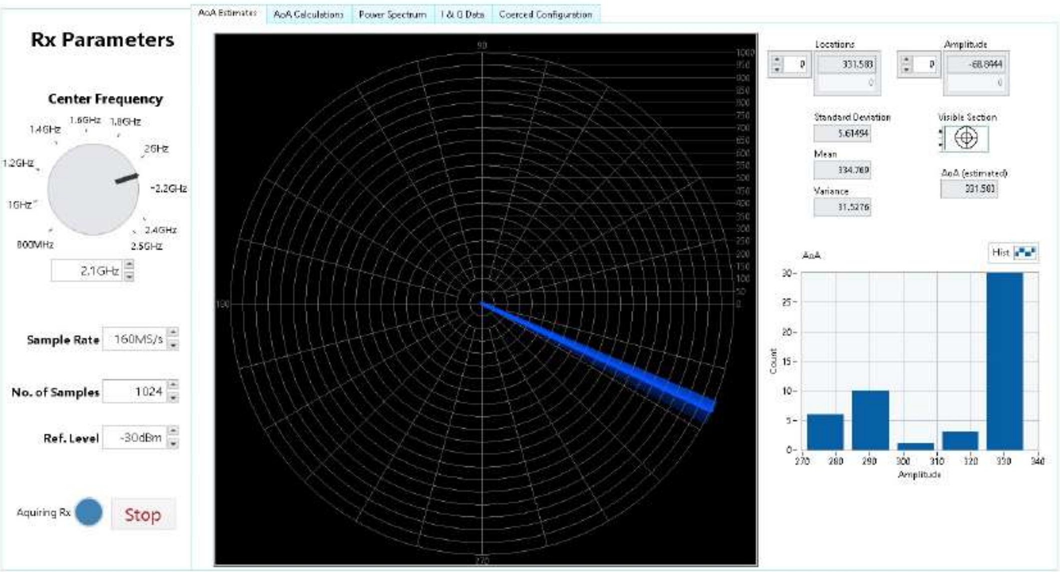
Waveform Name	Range Resolution	Doppler Resolution	Min Unambiguous Range	Max Unambiguous Range	Max Doppler
PRF_10kHz_PW_...	0.074948 km	10 kHz	0.074948 km	14.9896 km	5 kHz
LMF	0.029979 km	10 kHz	7.4948 km	14.9896 km	5 kHz
BarkerEncoding	0.01499 km	10 kHz	0.074948 km	14.9896 km	5 kHz

Figure 3-17: LFM Simulation with Windowing

3.3 Details of Final Working Prototype

The GUI of both the systems was developed in a manner which will give key insights regarding the signal processing chain and display the result, which is the target signal AOA in case of DF and the geolocation in case of Radar.

It is very important to note that the angle being shown in the DF GUI is from the reference antenna. The reference antenna is considered as 0 degrees; hence this angle needs to be calibrated using a north reference. The angle from the reference antennas increases towards the antenna which is chosen as second reference. Hence, there are 2 reference antennas. One, which is taken as 0 degrees. Second, towards which the angle increases. The first antenna must be aligned with north to establish an absolute reference.



Center Frequency: 2.1GHz

Sample Rate: 160MS/s

No. of Samples: 1024

Ref. Level: -30dBm

Locations: 0 | 331.583 | 0

Amplitude: 0 | -68.8944 | 0

Standard Deviation: 5.61494

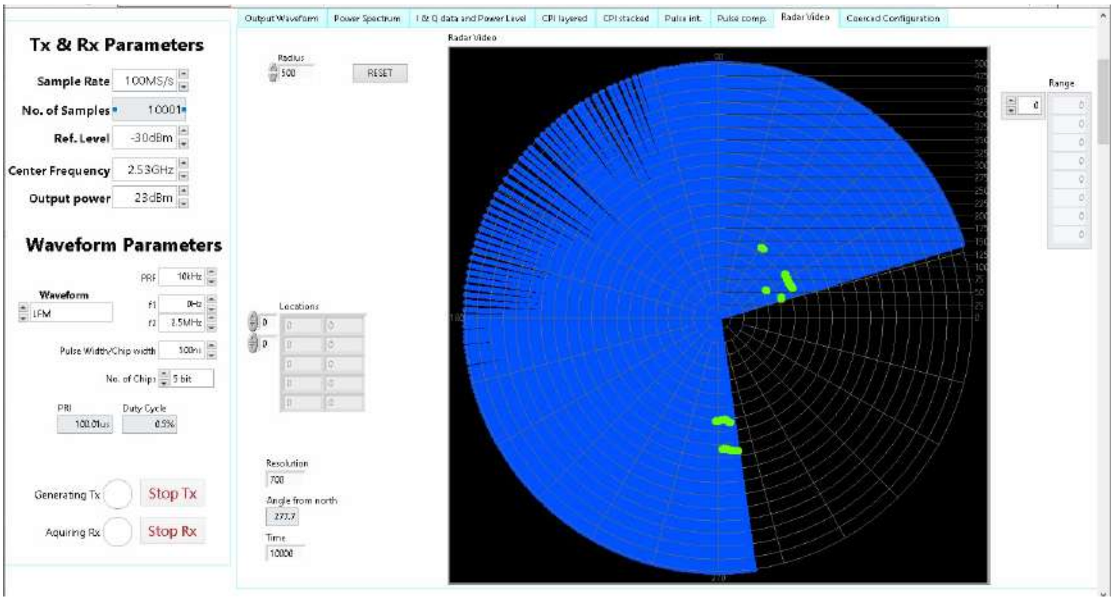
Mean: 334.769

Variance: 31.5276

AoA (estimated): 331.583

Figure 3-18: DF GUI

The angle being shown in the Radar GUI is from a north reference as a compass was integrated in the rotator module, to ensure correct north alignment when operating the Radar.



Tx & Rx Parameters

Sample Rate 100MS/s
No. of Samples 10001
Ref. Level -30dBm
Center Frequency 2.53GHz
Output power 23dBm

Waveform Parameters

PRF 10kHz
Waveform LFM
f1 0Hz
f2 2.5MHz
Pulse Width/Chip width 100ns
No. of Chips 5 bit
PRI 100.01us
Duty Cycle 0.5%
Generating Tx ○
Aquiring Rx ○

Radius 500
Radar Video
Locations 0 0
Resolution 700
Angle from north 277.7
Time 10000
Range 0

Figure 3-19: Radar GUI

The details of the final hardware set up can be seen in figure 3-20 and 3-21. Figure 3-22 shows both the systems being tested simultaneously for different types of targets.

Figure 3-20: 6 Element Switched Array For DF

The six-element array can be seen in figure 3-20, which is being used for passive detection. The independent Rx and Tx antennas can be seen in figure 3-21, which are being used for active detection.

Figure 3-21: Tx and Rx Antennas Mounted on A Rotator for Radar

Both the systems were tested using a single USRP, hence the USRP was not integrated with any hardware setup but was placed independently to ensure ease of testing and use.

Figure 3-22: Testing of Both the Systems

The testing was done on a remote site for two reasons. Firstly, line-of-sight with the target signals was required for passive detection. Secondly, an open area with minimal clutter was required to test the active system.

4.4 Summary

In this chapter the hardware and software design for the project was proposed and the hardware and software implementation were also explained. The key signal processing blocks were explained in detail alongside all key hardware components. The hardware setup and simulation of the antennas were presented.

Chapter 4

TOOLS AND TECHNIQUES

This chapter describes details about the hardware and software tools that have been used to implement the proposed project design given in chapter 3.

4.1 Hardware Tools

Hardware tools used in project includes an Antennas and Software defined radio with built-in RF front end and FPGA. This section describes the details about these tools.

4.1.1 USRP X310

The USRP X310 is a software-defined radio (SDR) platform developed by Ettus Research, a subsidiary of National Instruments. SDR refers to a radio communication system where traditional hardware components, such as mixers, modulators, and demodulators, are replaced with software algorithms running on a general-purpose computer [14]. The USRP X310 is designed for advanced SDR applications that require high-performance and wide frequency coverage. It features two high-speed analog-to-digital converters (ADCs) and two digital-to-analog converters (DACs), enabling full-duplex operation. The X310 also supports multiple radio frequency (RF) daughterboards, allowing it to operate over a wide frequency range, from DC to 6 GHz.

Figure 4-1: USRP X310 [14]

The device is built on a modular architecture, allowing users to customize and expand its capabilities by adding different daughterboards for specific frequency bands or applications [15]. It connects to a host computer via high-speed interfaces such as PCI Express or 10 Gigabit Ethernet, providing a high-throughput link for data streaming and control. The USRP X310 is commonly used in research, education, and industry for a variety of applications, including wireless communication systems prototyping, spectrum monitoring, cognitive radio, radar systems, and wireless sensor networks, among others. Its flexibility, high performance, and wide frequency range make it a versatile tool for experimenting with and implementing different wireless communication schemes. USRP is being used with UBX-160 daughter board in this project. It is equipped with Kintex 410T FPGA. UBX-160, is an RF daughterboard for the X310, which is equipped with an RF downconverter, upconverter, filters, and amplifiers.

Figure 4-2: UBX-160 [15]

4.1.2 LPDA

LPDA stands for Log-Periodic Dipole Array, which refers to a type of directional antenna commonly used in radio frequency (RF) communication and broadcasting. The LPDA antenna is characterized by its wide frequency bandwidth and relatively high gain, making it suitable for a range of applications. The LPDA antenna consists of a series of dipole elements arranged in a specific geometric pattern. The dipoles are progressively longer or shorter along the length of the antenna, creating a periodic structure. This design allows the antenna to maintain consistent performance over a wide frequency range [16].

Figure 4-3: LPDA Being Used in Radar Tx [17]

The LPDA antenna is often used in situations where a wide frequency coverage is required, such as in radio and television broadcasting, wireless communication systems, and spectrum monitoring. Its broadband nature enables it to receive and transmit signals across a broad range of frequencies, providing flexibility and efficiency in communication. The main advantages of LPDA antennas include:

1. **Wide frequency range:** LPDA antennas can cover a large frequency spectrum, typically from several megahertz (MHz) to several gigahertz (GHz), allowing them to be used in diverse applications without the need for frequent antenna replacements.
2. **Directional radiation pattern:** LPDA antennas exhibit a directional radiation pattern, focusing their energy in a particular direction. This characteristic is useful when aiming to communicate with or receive signals from specific locations.
3. **High gain:** LPDA antennas have relatively high gain, which refers to their ability to radiate or receive signals efficiently. This gain allows for increased signal strength and better communication range.

Center Frequency (MHz)	806-960/1710-2500mhz or customized
Gian (dBi)	10/11dB
Input Impendence (Ω)	55/45
V.S.W.R	≤1.5
Polarization Intensity	vertical

Figure 4-4: Specs of LPDA Being used for Radar Tx [17]

4.1.3 Parabolic Antenna

A parabolic antenna, also known as a parabolic reflector or dish antenna, is a type of antenna that uses a parabolic-shaped reflector to focus and direct radio waves. It is commonly used for long-range wireless communication, satellite communication, radar systems, and radio astronomy [18]. The parabolic antenna consists of a large curved metal or dielectric surface shaped like a paraboloid of revolution. The reflector has a concave shape, with the incoming radio waves being reflected and focused towards a single point known as the focal point or feed point. The feed point is usually located at the focus of the parabola and is where the antenna's transmitter or receiver is positioned. The key features and advantages of parabolic antennas are:

- **High gain:** Parabolic antennas can achieve high levels of gain, which is the ability to concentrate energy in a particular direction. The curved shape of the reflector enables the antenna to collect and focus signals, resulting in increased signal strength and improved long-range communication.
- **Directivity:** Parabolic antennas have a highly directional radiation pattern, which means they concentrate the transmitted or received energy into a narrow beam. This characteristic allows for precise targeting of signals, reducing interference and improving signal quality.
- **Narrow beamwidth**: The focused beam produced by a parabolic antenna has a narrow beamwidth, resulting in a more focused and concentrated signal. This helps in minimizing interference from other sources and improving the antenna's ability to receive or transmit signals over long distances.

4.1.4 RF LNA

RF LNA stands for Radio Frequency Low Noise Amplifier. It is an electronic device used to amplify weak signals received by an antenna in the radio frequency range while introducing minimal additional noise. LNAs are commonly employed in RF systems where weak signals need to be amplified before further processing or transmission. The main purpose of an RF LNA is to improve the signal-to-noise ratio (SNR) of the received signal. It amplifies the desired signal while adding as little noise as possible to maintain the integrity of the original signal [19]. This is crucial in applications such as wireless communication, radar systems, satellite communication, and sensitive receivers [19]. The LNA used in this project is ZX60-8008E-S+ made by MiniCiruits. Datasheet is attached in appendix.

Figure 4-5: Typical LNA [19]

4.2 Softwares and Simulation Tools

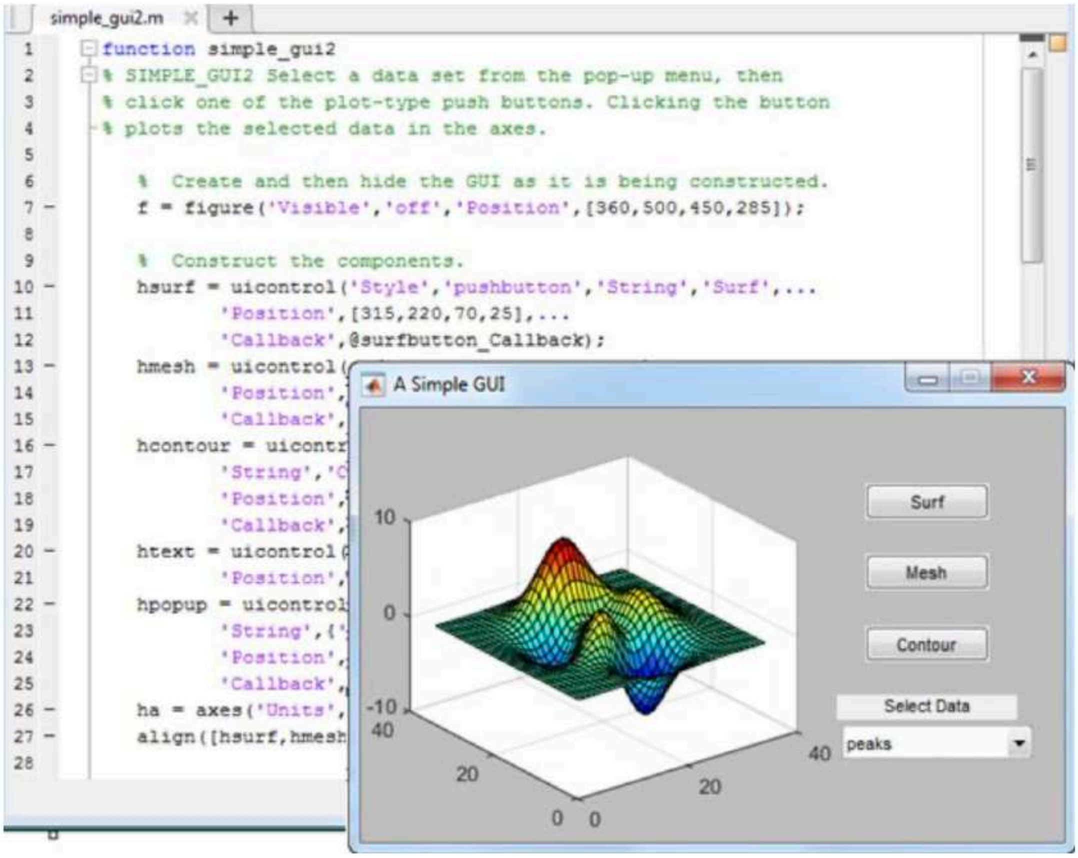
This section gives detail on the software tools used for implementation and simulation. Most of the software implementation was done in LabVIEW and LabVIEW FPGA. The simulation of the waveforms and matched filters was done in MATLAB.

4.2.1 MATLAB

MATLAB is a high-level programming language and development environment commonly used in various fields, including radar and direction-finding simulation. MATLAB provides a range of tools and functions for numerical computation, data analysis, visualization, and algorithm development. MATLAB allows users to generate simulated radar waveforms, such as continuous wave, pulsed, or frequency modulated signals [20].

These waveforms can be customized to match specific radar system parameters, such as pulse repetition frequency, bandwidth, and modulation schemes. MATLAB provides extensive signal processing capabilities for radar and DF applications. It offers functions for filtering, modulation and demodulation, range and Doppler processing, pulse compression, and beamforming. These functions enable users to implement various algorithms and techniques for signal analysis and target detection.

MATLAB allows users to develop models of radar systems and simulate their performance. This includes modeling the radar hardware components, such as antennas, transmitters, receivers, and signal processors, as well as environmental factors like clutter, noise, and target characteristics. The simulated radar system can be used to evaluate system performance, optimize parameters, and assess the impact of different factors on radar measurements. MATLAB can be used to simulate and analyze direction finding algorithms and techniques. It enables users to model antenna arrays, generate received signals from multiple directions, and implement algorithms for estimating the direction of arrival (DOA) of signals.



```
function simple_gui2
% SIMPLE_GUI2 Select a data set from the pop-up menu, then
% click one of the plot-type push buttons. Clicking the button
% plots the selected data in the axes.

   %  Create and then hide the GUI as it is being constructed.
   f = figure('Visible','off','Position',[360,500,450,285]);

   %  Construct the components.
   hsurf = uicontrol('Style','pushbutton','String','Surf',...
          'Position',[315,220,70,25],...
          'Callback',@surfbutton_Callback);
   hmesh = uicontrol(
          'Position',
          'Callback',
   hcontour = uicontr
          'String','C
          'Position',
          'Callback',
   htext = uicontrol(
          'Position',
   hpopup = uicontrol
          'String',{
          'Position',
          'Callback',
   ha = axes('Units',
   align([hsurf,hmesh
```

Figure 4-6: MATLAB IDE [21]

4.2.2 LabVIEW

LabVIEW is a graphical programming environment developed by National Instruments. It is widely used for system design, control, and data acquisition in various fields, including RF signal processing. LabVIEW allows users to create virtual instruments (VIs) by connecting graphical icons, called nodes, to form a dataflow diagram. This visual programming approach makes it easier for users to develop and implement complex systems without extensive coding. Data Acquisition and Analysis: LabVIEW offers tools for acquiring and processing RF data. It supports a wide range of data acquisition devices, including RF front ends, analog-to-digital converters (ADCs), and digital-to-analog converters (DACs). Users can design custom data acquisition systems and implement real-time signal processing algorithms for RF applications [22].

LabVIEW's signal processing libraries and functions can be utilized for tasks such as filtering, demodulation, spectral analysis, and modulation/demodulation. Visualization and User Interfaces: LabVIEW provides extensive graphical capabilities for visualizing and presenting RF signal data. Users can create interactive user interfaces, custom displays, and data visualization tools. These UIs can be used for real-time monitoring, control, and analysis of RF signals.

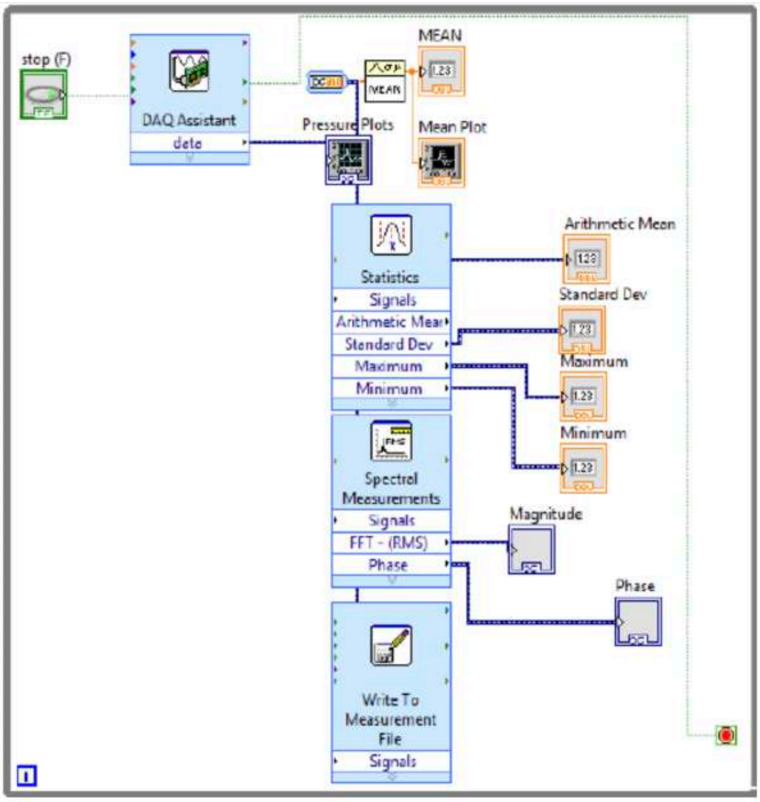


Figure 4-7: LabVIEW [23]

4.3 Summary

The key software tool being used in this project for implementation of the signal processing blocks in LabVIEW, and USRP X310 is the key hardware block, since the downconverter, ADC, and FPGA are on it.

Chapter 5

PROJECT RESULTS AND EVALUATION

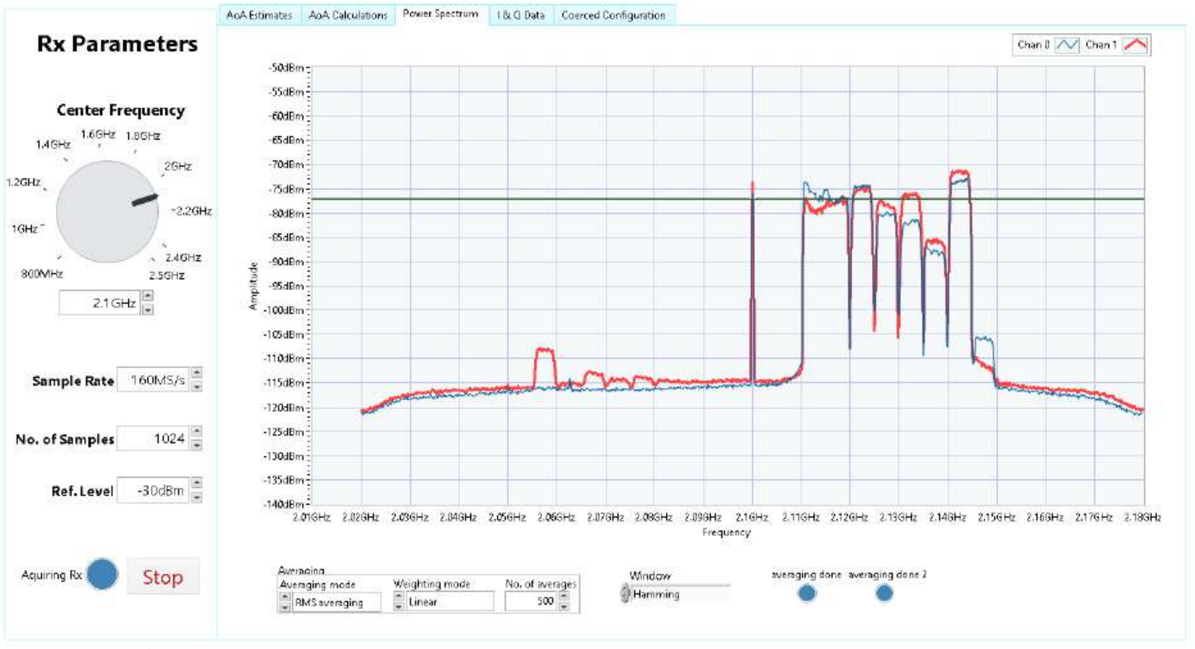
This chapter presents the results of the performance for both the systems in different scenarios and for different targets.

5.1 Presentation of the findings

The following sections present the results of both the systems, active and passive.

5.1.1 Passive Detection

Figure 5-1 demonstrates that after averaging the FFT from both the adjacent elements, there is a considerable difference in power, which is used to determine the angle of arrival.



Center Frequency 2.1 GHz

Sample Rate 160MS/s

No. of Samples 1024

Ref. Level -30dBm

Averaging mode RMS averaging

Weighting mode Linear

No. of averages 500

Window Hamming

Figure 5-1: FFT Averaging

Figure 5-2 demonstrates the time domain signals and the power levels of the signals. It is very difficult to differentiate both the signals with reference to time, hence it is imperative to calculate the relative power level in the frequency domain.


Rx Parameters

Center Frequency: 2.1 GHz

Sample Rate: 160MS/s

No. of Samples: 1024

Ref. Level: -30dBm

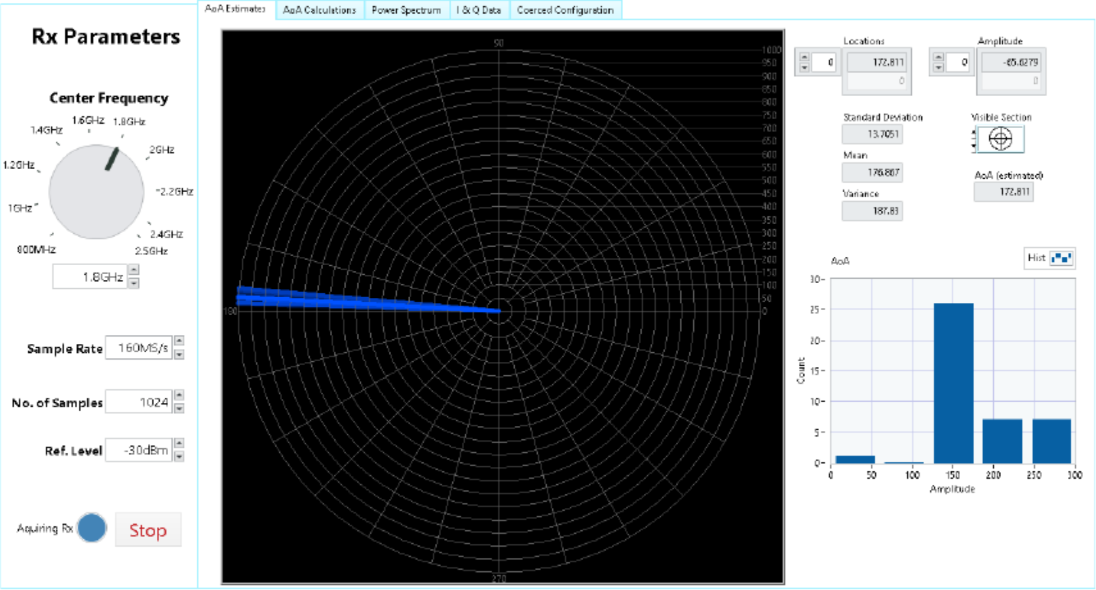
Figure 5-2: Time Domain Signal

Since the AOA is relative to the direction of the reference antenna, the angle shown in the results does not hold any significance unless the angle of the reference element is north aligned, but regardless the performance of the system can be measured using the variance of the angle. The test signal was a 4G signal of the closest tower, whose AOA was being calculated. In order to test the accuracy of the system, the array of antennas was rotated by 170 degrees.

Figure 5-3 displays the results of the first test case where the AOA of the signal is about 170 degrees, after rotating the antennas by 170 degrees, the AOA is now 340 degrees. These results are in line with the test scenarios.

In figures 5-3 and 5-5, the estimated AOA of the signal can be observed. The variance of the angle was 46 degrees, which is in line with our original hypothesis; accuracy depends on the number of elements in the switched array (and also the power level of the signal). In figure 5-4 and 5-6, it can be seen how regression is used to estimate the AOA. Regression is an imperative part of the signal processing chain, as it increases the accuracy of the AOA.

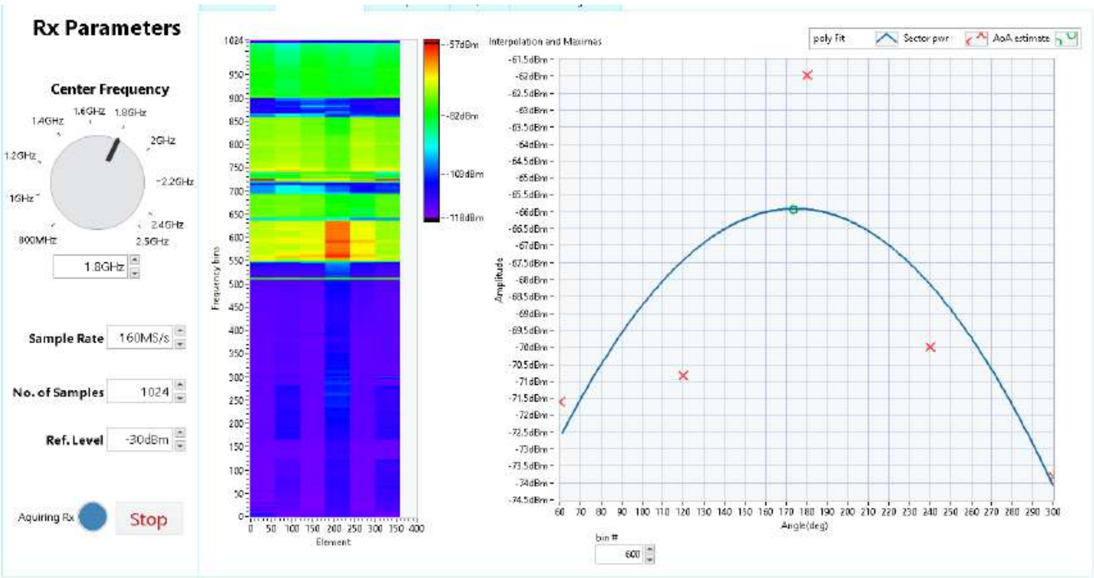
The FFT vs element graph can also be seen which clearly indicates that the maximum power lies in one element. After rotating the array, the maximum power changes from element 3 to element 0 in the respective frequency bin.



Center Frequency: 1.8GHz
Sample Rate: 160MS/s
No. of Samples: 1024
Ref. Level: -30dBm
Locations: 0 172.811
Amplitude: 0 -65.6279
Standard Deviation: 13.7051
Mean: 176.867
Variance: 187.83
AoA (estimated): 172.811

Figure 5-3: Target AOA Estimation (Test Case 1)

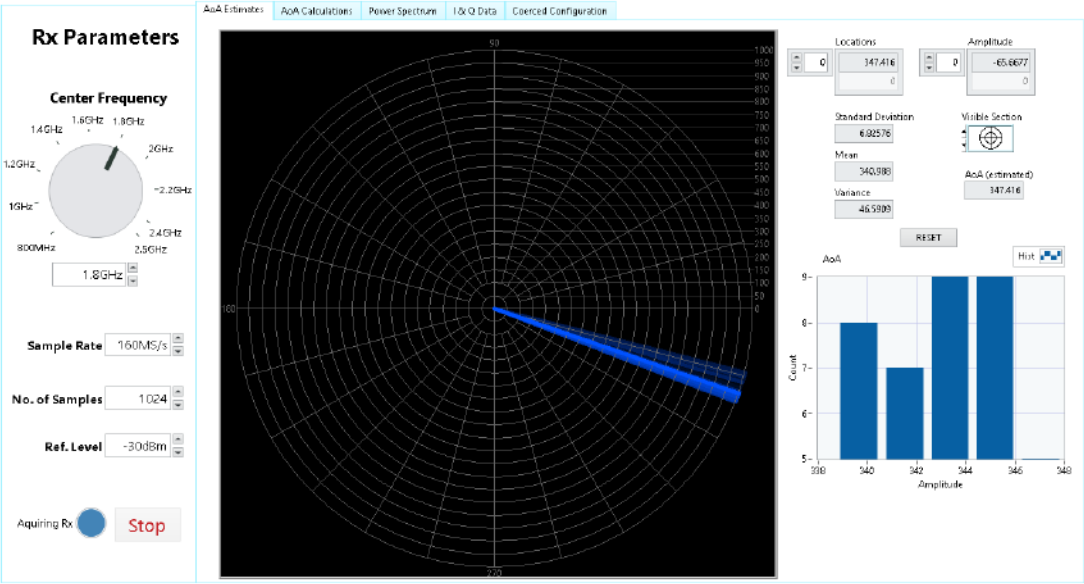
Figure 5-4 displays variance as 187 degrees. The array was being rotated for testing purposes and the AOA buffer was not reset before recording the results hence the incorrect variance. On the plot, all the estimated directions are around 176 degrees, yet the variance is 187. Hence this result will be excluded from the results.



Center Frequency: 1.8GHz
Sample Rate: 160MS/s
No. of Samples: 1024
Ref. Level: -30dBm
bin #: 600

Figure 5-4: Target AOA Regression (Test Case 1)

The target signal in test case 1 and 2 is 4G LTE Band 3, which operates at 1800 MHz. This is also evident by looking at the center frequency in the figures.


Rx Parameters

Center Frequency: 1.8GHz

Sample Rate: 160MS/s

No. of Samples: 1024

Ref. Level: -30dBm

Locations: 0 — 347.416, 0

Amplitude: 0 — -65.6677, 0

Standard Deviation: 6.82576

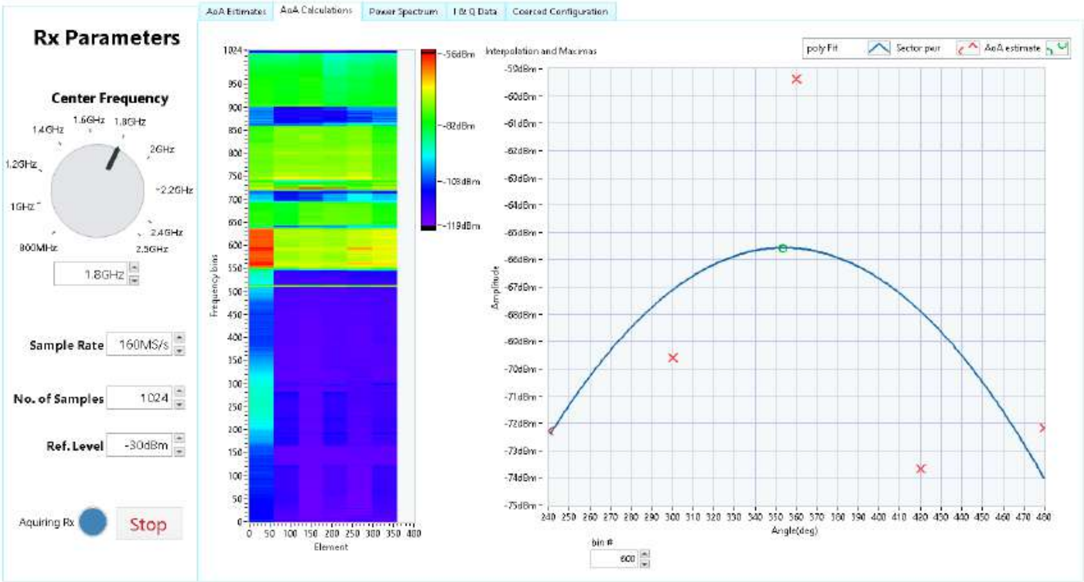
Mean: 340.988

Variance: 46.5909

AoA (estimated): 347.416

Figure 5-5: Target AOA Estimation (Test Case 2)

Test case 1 and 2, successfully demonstrate that the passive system is functioning as expected and estimates the AOA correctly within a certain margin of error. The details of the results are presented in table 5-1.


Rx Parameters

Center Frequency: 1.8GHz

Sample Rate: 160MS/s

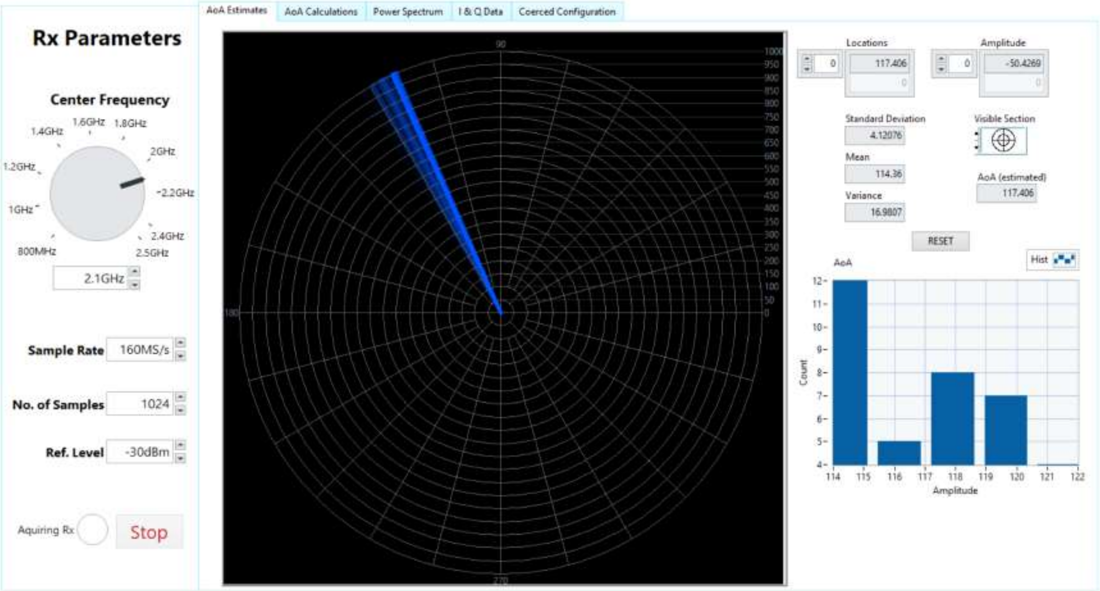
No. of Samples: 1024

Ref. Level: -30dBm

bin #: 600

Figure 5-6: Target AOA Regression (Test Case 2)

The target signal in test case 3 is 3G UMTS Band 1, which operates at 2100 MHz. This is also evident by looking at the center frequency in the figures.



Rx Parameters

Center Frequency 2.1GHz

Sample Rate 160MS/s

No. of Samples 1024

Ref. Level -30dBm

Locations 117.406

Amplitude -50.4269

Standard Deviation 4.12076

Mean 114.36

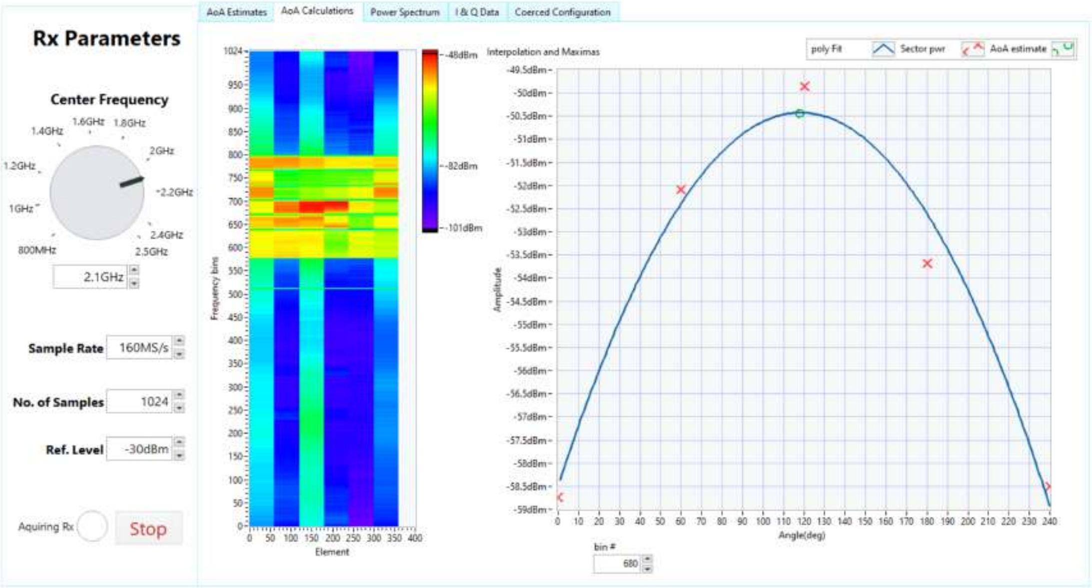
Variance 16.9807

Visible Section

AoA (estimated) 117.406

Figure 5-7: Target AOA Estimation (Test Case 3)

In test case 3, the power (-50dBm) of the signal is greater than test case 1 and 2 (-66dBm), because of this the regression is more accurate and fits the data with less residual error. This is also evident by observing the variance, which is 17 degrees for test case 3, compared to 46 degrees for test case 2. It can clearly be observed that **increasing the SNR improves the performance of the system significantly.**



Rx Parameters

Center Frequency 2.1GHz

Sample Rate 160MS/s

No. of Samples 1024

Ref. Level -30dBm

bin # 680

Figure 5-8: Target AOA Regression (Test Case 3)

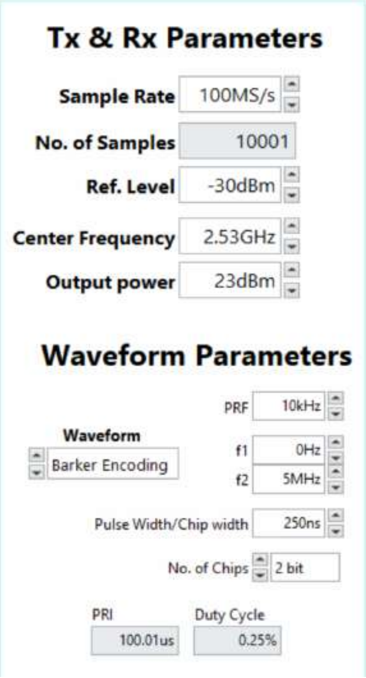
The results of all 3 test cases have been presented in table 5-1.

Table 5-1: Results for Passive Detection

Test Signal	Center Frequency	Power Level	AOA Actual	AOA Estimation	AOA Variance	AOA Error
4G	1800MHz	-66dBm	170°	177°	-°	1.94%
4G	1800MHz	-66dBm	340°	341°	46°	0.27%
3G	2100MHz	-50dBm	120°	114°	16°	1.67%

5.1.2 Active Detection

The first step was generating the transmission waveform. In the GUI there is an option to control the PRI size, pulse width, intra pulse modulation type and modulation parameters. The next is to compare the signal processing gain and eventually target detection probability for these different modulation types. The receive signal processing chain is fixed; PRI extraction, coherent pulse integration, pulse compression, and STC are implemented in this chain.



Tx & Rx Parameters

Sample Rate 100MS/s

No. of Samples 10001

Ref. Level -30dBm

Center Frequency 2.53GHz

Output power 23dBm

Waveform Parameters

PRF 10kHz

Waveform Barker Encoding

f1 0Hz

f2 5MHz

Pulse Width/Chip width 250ns

No. of Chips 2 bit

PRI 100.01us

Duty Cycle 0.25%

Figure 5-9: Tx Waveform Parameters Tab

5.1.2.1 Barker Encoding 5-bit

The transmission pulse can be seen in figure 5-10, the pulse parameters are also visible. The chip width was set at 100ns, which results in a pulse width of 500ns. This gives a range resolution of 0.015km.

Tx & Rx Parameters

Sample Rate: 100MS/s
No. of Samples: 10001
Ref. Level: -30dBm
Center Frequency: 2.53GHz
Output power: 23dBm

Waveform Parameters

PRF: 10kHz
Waveform: Barker Encoding
f1: 0Hz
f2: 2.5MHz
Pulse Width/Chip width: 100ns
No. of Chips: 5 bit
PRI: 100.01us
Duty Cycle: 0.1%

Figure 5-10: Barker Encoding 5-Bit Transmission Pulse

The received signal and power level can also be seen in the time domain in figure 5-11. The echo can also be seen, but the echo has a very low SNR.

Tx & Rx Parameters

Sample Rate: 100MS/s
No. of Samples: 10001
Ref. Level: -30dBm
Center Frequency: 2.53GHz
Output power: 23dBm

Waveform Parameters

PRF: 10kHz
Waveform: Barker Encoding
f1: 0Hz
f2: 2.5MHz
Pulse Width/Chip width: 100ns
No. of Chips: 5 bit
PRI: 100.01us
Duty Cycle: 0.1%

Figure 5-11: Received PRI and Power Level for 5-Bit Barker

The received PRIs can be seen in figure 5-12, once the PRIs are stacked together, the reflected pulse becomes obvious since it is present in all the PRIs, and it cannot be negated as an artifact.

Tx & Rx Parameters

Sample Rate 100MS/s

No. of Samples 10001

Ref. Level -30dBm

Center Frequency 2.53GHz

Output power 23dBm

Waveform Parameters

PRF 10kHz

Waveform Barker Encoding

f1 0Hz

f2 2.5MHz

Pulse Width/Chip width 100ns

No. of Chips 5 bit

PRI 100.01us

Duty Cycle 0.1%

Figure 5-12: Stacked PRIs for 5-Bit barker

Once the pulse integration is calculated to the received signal, the amplitude of the echo is very evident. The calculated gain is approximately 50, which is in line with our theoretical calculation since 50 pulses are being coherently integrated.

Tx & Rx Parameters

Sample Rate 100MS/s

No. of Samples 10001

Ref. Level -30dBm

Center Frequency 2.53GHz

Output power 23dBm

Waveform Parameters

PRF 10kHz

Waveform Barker Encoding

f1 0Hz

f2 2.5MHz

Pulse Width/Chip width 100ns

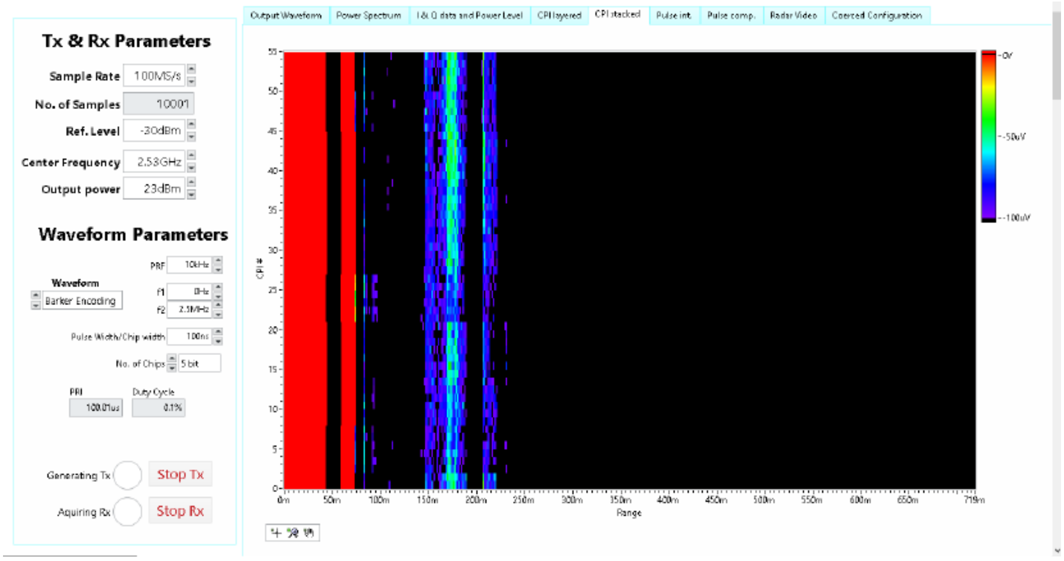
No. of Chips 5 bit

PRI 100.01us

Duty Cycle 0.1%

Figure 5-13: Pulse Integration for 5-Bit Barker

Figure 5-14 demonstrates the PRIs stacked with respect to time, which clearly separates the echo from noise and artifacts, because the reflection persists over time.



Tx & Rx Parameters

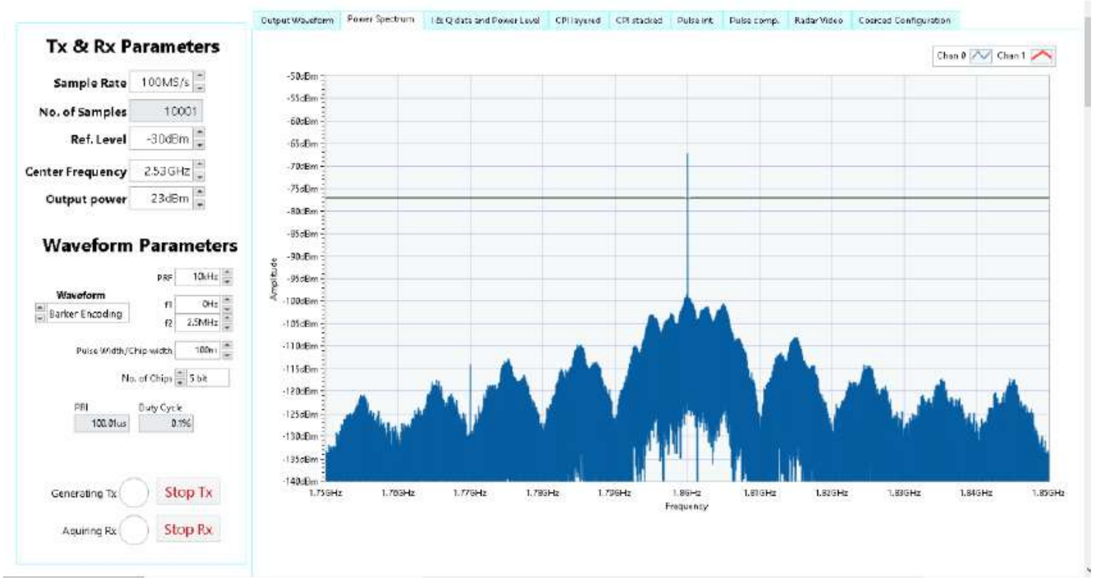
Sample Rate: 100MS/s
No. of Samples: 10001
Ref. Level: -30dBm
Center Frequency: 2.53GHz
Output power: 23dBm

Waveform Parameters

PRF: 10kHz
Waveform: Barker Encoding
f1: 0Hz
f2: 2.5MHz
Pulse Width/Chip width: 100ns
No. of Chips: 5 bit
PRI: 100.01us
Duty Cycle: 0.1%
Generating Tx
Aquiring Rx

Figure 5-14: PRIs Stacked Together with Reference to Time (PRI Number) For 5-Bit Barker

The FFT of the transmission pulse can be observed in figure 5-15, which is according to the simulations presented in chapter 3.



Tx & Rx Parameters

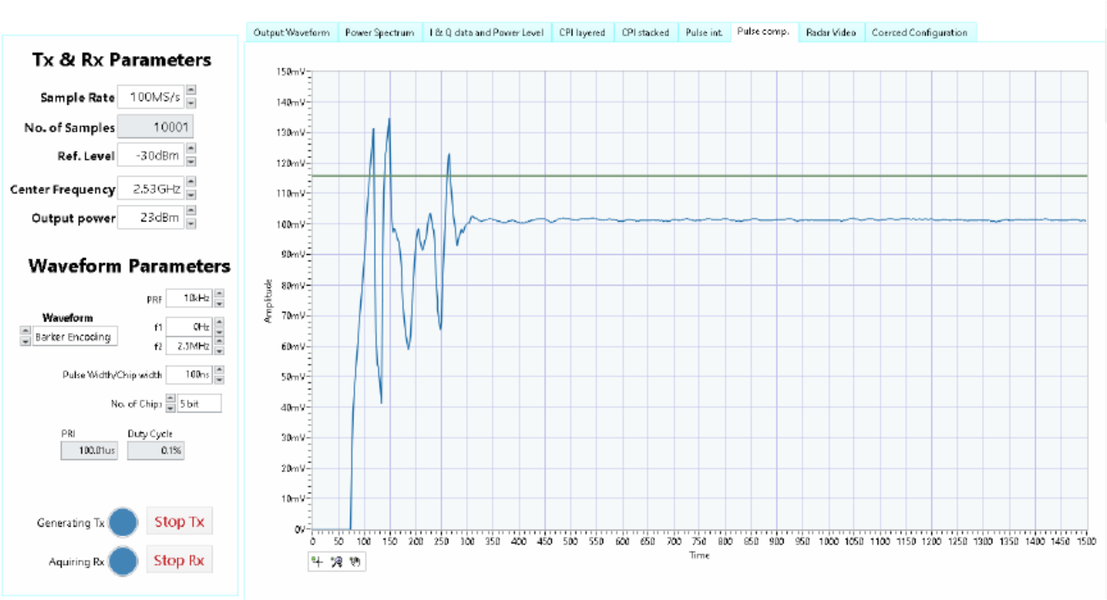
Sample Rate: 100MS/s
No. of Samples: 10001
Ref. Level: -30dBm
Center Frequency: 2.53GHz
Output power: 23dBm

Waveform Parameters

PRF: 10kHz
Waveform: Barker Encoding
f1: 0Hz
f2: 2.5MHz
Pulse Width/Chip width: 100ns
No. of Chips: 5 bit
PRI: 100.01us
Duty Cycle: 0.1%
Generating Tx
Aquiring Rx

Figure 5-15: FFT of 5-bit barker

The last block in the receive signal processing chain is pulse compression, which significantly improves the SNR and clearly highlights the target features. The results of pulse compression indicate the presence of 3 targets (which have crossed the threshold). The target is present at 150m, which can also be seen in figure 5-14. The peaks are very sharp, since 5-bit barker is being used as the transmission waveform. The target peak has the highest amplitude at 150m. The peaks at 100 and 260m also signify a target present at these ranges. These echoes are not visible in figure 5-14 due to scaling of the z-axis.



Tx & Rx Parameters

Sample Rate: 100MS/s
No. of Samples: 10001
Ref. Level: -30dBm
Center Frequency: 2.53GHz
Output power: 23dBm

Waveform Parameters

PRF: 10kHz
Waveform: Barker Encoding
f1: 0Hz
f2: 2.5MHz
Pulse Width/Chip width: 100ns
No. of Chips: 5 bit
PRI: 100.01us
Duty Cycle: 0.1%

Figure 5-16: Pulse Compression For 5-Bit Barker

The signal processing gain for pulse compression is 26, so a total gain (pulse integration and pulse compression) of approximately 76, which is **37dB.**

5.1.2.2 No Modulation, LFM, and 2-bit Barker

In case of no modulation, all the similar results have been displayed; the pulse integration gain is the same as before, but the matched filtering gain is significantly less. An important point to note is that during matched filtering, the peaks of the target locations are not very sharp, which significantly reduced range resolution.

The results of LFM have been displayed in appendix C. The results for LFM display similar characteristics but the pulse compression gain is less than that of barker.

The results of 5-bit barker, LFM, and No Modulation were recorded in the same testing environment and for the same targets. But the result for 2-bit barker was recorded in a different environment for different targets.

Tx & Rx Parameters

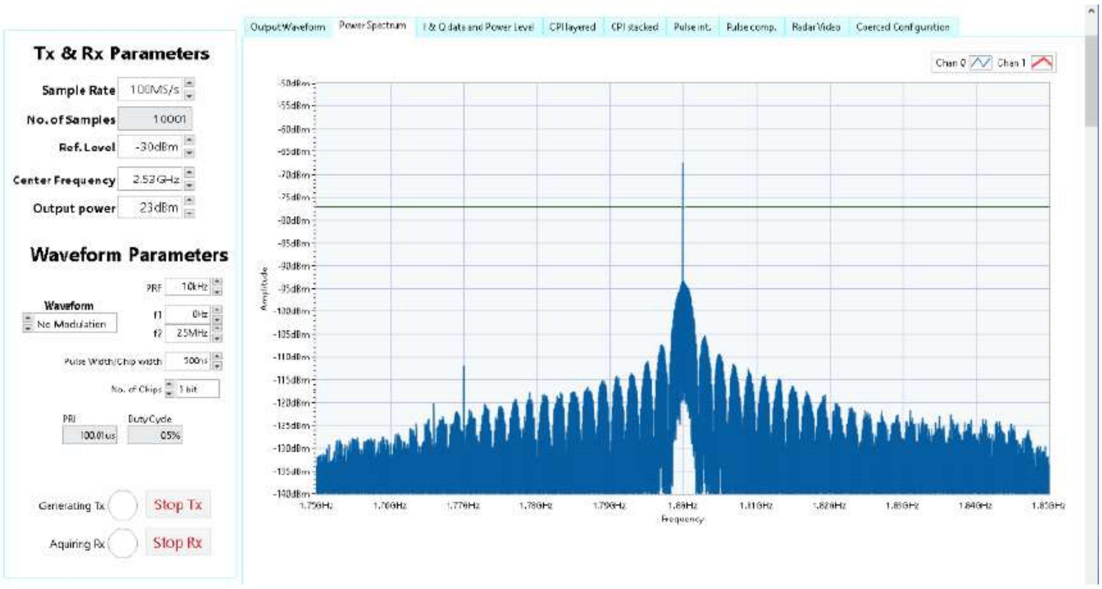
Sample Rate 100MS/s
No. of Samples 10001
Ref. Level -30dBm
Center Frequency 2.53GHz
Output power 23dBm

Waveform Parameters

PRF 10kHz
Waveform No Modulation
f1 0Hz
f2 2.5MHz
Pulse Width/Chip width 500ns
No. of Chips 3 bit
PRI 100.01us
Duty Cycle 0.5%

Figure 5-17: Basic Pulse Transmission Pulse

The transmission signal can be observed in figure 5-17.



Tx & Rx Parameters

Sample Rate 100MS/s
No. of Samples 10001
Ref. Level -30dBm
Center Frequency 2.53GHz
Output power 23dBm

Waveform Parameters

PRF 10kHz
Waveform No Modulation
f1 0Hz
f2 2.5MHz
Pulse Width/Chip width 500ns
No. of Chips 1 bit
PRI 100.01us
Duty Cycle 05%

Figure 5-18: FFT Of Basic Pulse

The FFT of the transmission signal is presented in figure 5-18, the results are in ine with the simulations presented in chapter 3.

Tx & Rx Parameters

Sample Rate 100MS/s
No. of Samples 10001
Ref. Level -30dBm
Center Frequency 2.53GHz
Output power 23dBm

Waveform Parameters

PRF 10kHz
Waveform No Modulation
f1 0Hz
f2 2.5MHz
Pulse Width/Chip width 500ns
No. of Chips 3 bit
PRI 100.01us
Duty Cycle 0.5%

Figure 5-19: Returned PRIs

The PRIs in figure 5-19 indicates that the echo is persistent at the same location, signifying that it is indeed a valid target.

Tx & Rx Parameters

Sample Rate 100MS/s
No. of Samples 10001
Ref. Level -30dBm
Center Frequency 2.53GHz
Output power 23dBm

Waveform Parameters

PRF 10kHz
Waveform No Modulation
f1 0Hz
f2 2.5MHz
Pulse Width/Chip width 500ns
No. of Chips 3 bit
PRI 100.01us
Duty Cycle 0.5%

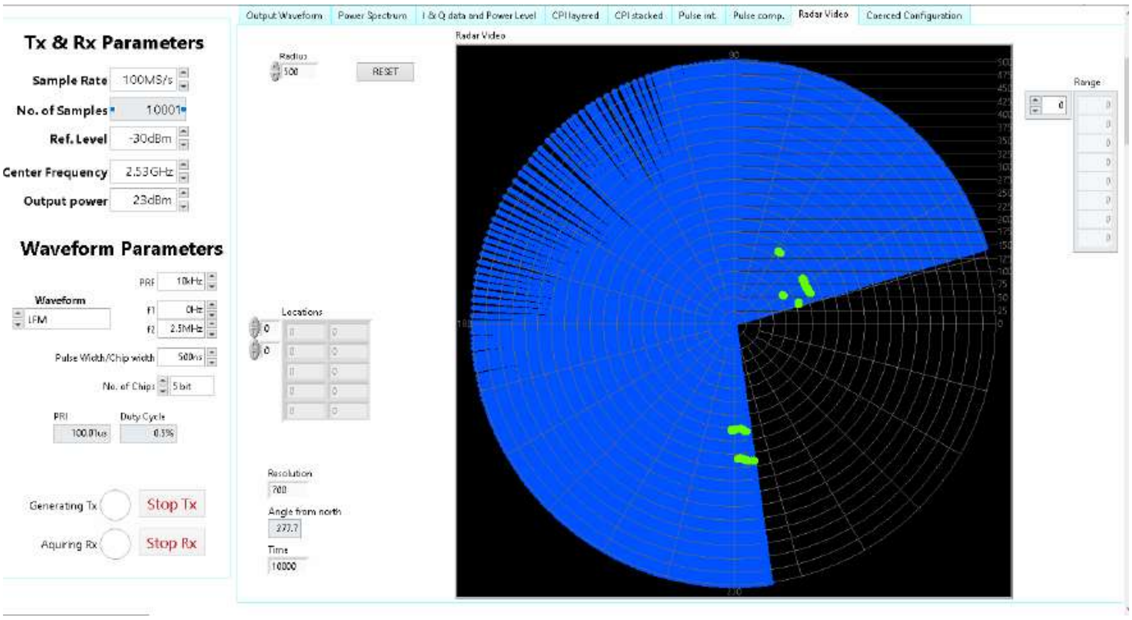
Figure 5-20: Matched Filtering of Basic Pulse

The matched filter output signifies that a target is present at 150m, same as before. But notice how the peak is not as sharp, and only one target is visible, the **matched filter was unable to resolve the rest of the targets** in the case of no modulation.

5.1.2.3 Target Detections

The target detection was accurate for the radar, the range measurement was made using the threshold set on pulse compression output, and the angular measurement was made using the compass.

Two tests were conducted to verify the target detection of the active system. In test case one there were a total of 2 isolated targets in the radars range, but the targets have many features at different ranges, as a consequence each individual targets shows up as a cluster of targets. The range accuracy was ±10m and the angular accuracy was 2.5 degrees. Nonetheless, the radar successfully detected both the targets.



Tx & Rx Parameters

Sample Rate: 100MS/s
No. of Samples: 10001
Ref. Level: -30dBm
Center Frequency: 2.53GHz
Output power: 23dBm

Waveform Parameters

PRF: 10kHz
Waveform: LFM
F1: 0Hz
F2: 2.5MHz
Pulse Width/Chip width: 500ns
No. of Chips: 5 bit
PRI: 100.01us
Duty Cycle: 0.5%
Generating Tx
Aquring Rx

Radius: 500
Locations: 0, 0
Resolution: 700
Angle from north: 277.7
Time: 10000

]

Figure 5-21: Targets Detected (Test Case 1)

The Radar display can be seen in figure 5-22, where both the targets are evident with their respective range and angle from north. The blue line indicates the area that has been scanned recently, and the green dot indicates the presence of a target. The actual testing scenario has also been shown in figure 5-23, highlighting distance and location of the targets with respect to the Radar.

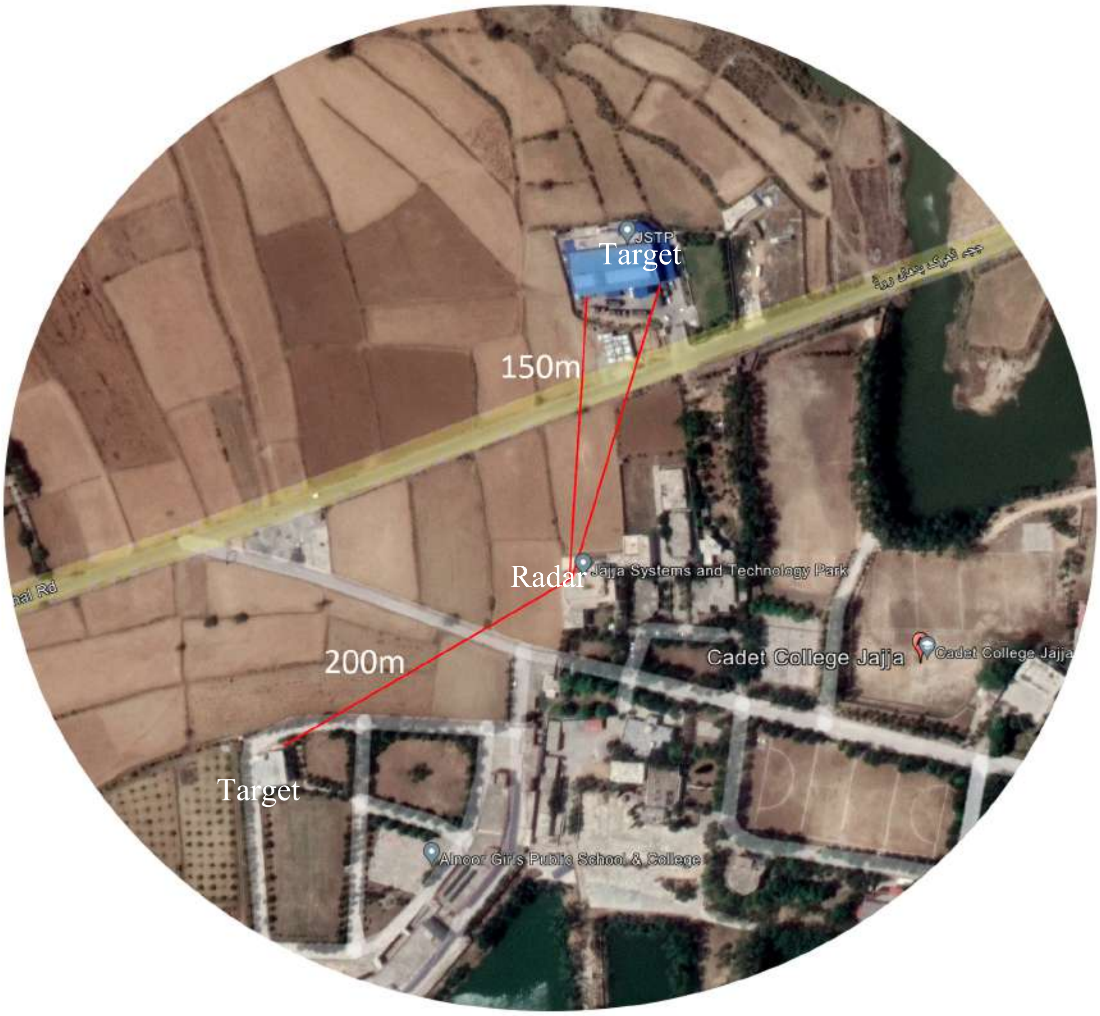
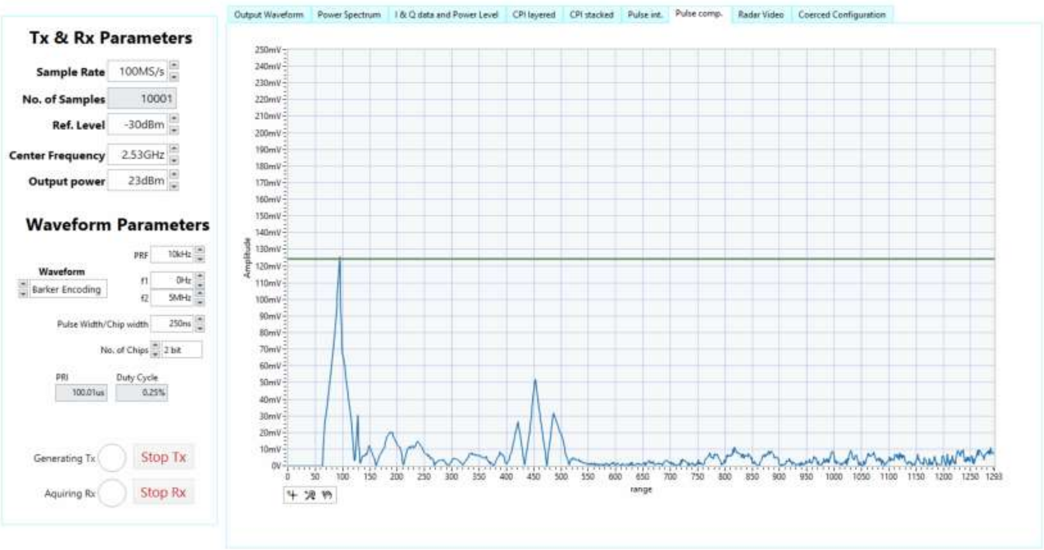


Figure 5-22: Actual Target Locations (Test Case 1)

For test case two is can be observed that a different location with a different target was used to test the Radar. The waveform used for this test was a 2-bit barker. The pulse compression output can be seen in figure 5-24, which indicates the presence of targets at 100m and 450m, again, these results are accurate and in line with the test scenario. Figure 5-23 highlights the targets and their respective distances from the Radar.

There were many targets present in this scenario, but the radar was facing towards to the sky at an angle so ensure only the two high-rise targets were exposed to the vertical beamwidth.



Tx & Rx Parameters

Sample Rate: 100MS/s

No. of Samples: 10001

Ref. Level: -30dBm

Center Frequency: 2.53GHz

Output power: 23dBm

Waveform Parameters

Waveform: Barker Encoding

PRF: 10kHz

f1: 0Hz

f2: 5MHz

Pulse Width/Chip width: 250ns

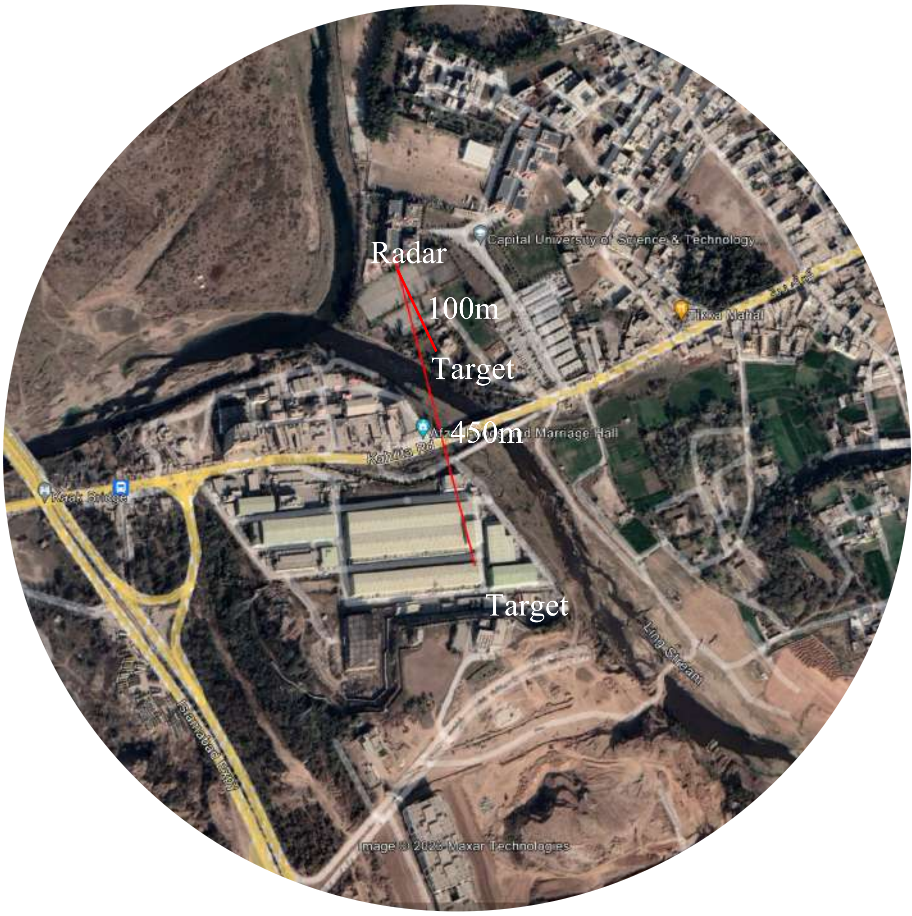
No. of Chips: 2 bit

PRI: 100.01us

Duty Cycle: 0.25%

Figure 5-23: Target Detection (Test Case 2)

With these two test cases, the verification of the Radar is complete as it has met all initial specifications given in Table 1-1.



s

Figure 5-24: Actual Target Locations (Test Case 2)

5.2 Discussion on the Findings

The following section presents an analysis on the findings of the detailed testing including the limitations of the prototype. This section also demonstrates the

5.2.1 Comparison with Initial Project Specifications

All the project specifications are met except the range of the radar, which is significantly less than initially estimated.

5.2.2 Reasoning for Short Comings

A pulsed power amplifier could not be sourced due to logistical challenges, which is the reason behind the limited range of the Radar.

5.3 Limitations of the Working Prototype

In this system only amplitude-based DF was implemented with a 6-element array, despite interpolation and curve fitting, the accuracy is inherently limited to the number of elements in the array, and their respective beam widths. Amplitude based DF is also very sensitive to reflections as amplitude variations affect the results significantly.

Due to logistical challenges, a pulsed power amplifier could not be acquired for the Radar, which reduced the range of the radar significantly. Also, the targets could not be segregated from clutter, because doppler was not implemented.

Since both algorithms were not implemented in FPGA, there was a huge speed cost, which caused the passive system's performance to significantly degrade for moving targets.

For active system, since the PRI acquisition was not implemented in FPGA, doppler could not be implemented which is an integral part of any radar.

5.4 SDG Goals Progress

SDG goals specified in chapter 1, have been met since the system's functionality is as intended.

Table 5-2: SDG Progress

Goal No.	**Goal**	**How it has been achieved**
9	Industry Innovation and Infrastructure	The project has established the need for a hybrid architecture, which is to promote innovation in the industry.
11	Sustainable cities and communities	DF system can be implemented at any airport for secure landing of planes, to ensure no quadcopter is nearby which can be a safety concern for the plane and its passengers. Although this radar **cannot be used as automotive radar** since it lacks the resolution. (automotive radars are mmWave)
16	Peace, justice, and strong institutions	Radar and DF both can be used by enforcement agencies to determine the presence of any threat. In times of war it can be used to intercept communication.

Chapter 6

CONCLUSION AND FUTURE WORK

Both the systems were successfully designed, implemented, and evaluated. This chapter concludes the project, taking into consideration the initial specifications, results, findings, and shortcomings of both the systems.

6.1 Conclusion

After testing the active and passive systems it can be concluded, as suspected, that both are very different in terms of their fundamental principles yet are used for the same purposes; to detect targets.

Passive detection can only identify the angle of arrival of the RF signal incoming from the target, hence indicating the direction of the target from sensing element (antenna). Although, two or more passive detection systems can be set up and the geolocation of the target can be estimated using triangulation. Detection of target is based on the power of RF signal being transmitted by the target itself, and signal processing techniques. Passive systems can operate without transmitting any RF signal, hence can go by undetected.

Active detection systems transmit RF signals and estimate the geolocation of the target using the received echo of the signal. The velocity of the target can also be estimated, which is an added benefit, by measuring the doppler frequency of the received signal. Detection of the target depends on the RCS of the target, the distance of the target form the system, RF transmission power, and signal processing techniques which improve SNR. Since RF is being transmitted, the system can inherently be detected easily, hence is not suited for in situations where the user wants to shield their presence.

Active and passive detection cannot be compared directly, as they are fundamentally different, but because they are similar in what they are trying to achieve, a hybrid system which benefits from both can be recommended.

Table 6-1: Area of Strengths and Weaknesses

Scenario	**Passive System**	**Active System**
Emitting targets with small RCS	strong	Weak
Emitting targets with large RCS	strong	Strong
Non-Emitting targets with small RCS	Not possible	Weak
Non-Emitting targets with large RCS	Not possible	Strong

In the modern world it is very rare to find a non-emitting target, and even more difficult to find a non-emitting target with a small RCS. Even unmanned drones have large RCS and are active communicating, if not with the user, with the satellite for GPS coordinates. Modern jets use specialized Radar-absorbing material to stay undetected, but passive techniques can easily detect them since RF communication is at the core of any airborne object. Hence a combination of active and passive techniques is essential for a complete multirole hybrid system.

Table 6-1 highlights how in a multirole system, the benefits of one system can compensate for the weakness of the other system. This implies the importance of a cohesive multirole hybrid system which can use both technologies to detect targets with a higher probability of detection and higher accuracy.

6.2 Future Work and Recommendations

Taking into consideration the limitations of amplitude-based DF, a phased based approach must be implemented parallel to the existing system. Combining both gives us the best passive system. Amplitude based approach does not require a high SNR, whereas phase-based approach can give better accuracy. Since both the techniques have their own benefits, it is imperative to implement both of them simultaneously to have benefits of both.

For active detection is very important to implement doppler to separate targets from clutter, and to implement more complex signal processing techniques such as sidelobe rejection, variable PRI, and short medium & long pulse. A pulsed power amplifier must also be sourced, as that will improve the range significantly.

REFERENCES

[1] M. I. Skolnik, "Fifty years of radar," in Proceedings of the IEEE, vol. 73, no. 2, pp. 182-197, Feb. 1985, doi: 10.1109/PROC.1985.13132.

[2] “Radar,” Wikipedia, https://en.wikipedia.org/wiki/Radar (accessed Jun. 11, 2023).

[3] S. Kobayashi and T. Iguchi, "Variable pulse repetition frequency for the Global Precipitation Measurement Project (GPM)," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 41, no. 7, pp. 1714-1718, July 2003, doi: 10.1109/TGRS.2003.813700.

[4] Z. Qu, C. Hou, C. Hou and W. Wang, "Radar Signal Intra-Pulse Modulation Recognition Based on Convolutional Neural Network and Deep Q-Learning Network," in *IEEE Access*, vol. 8, pp. 49125-49136, 2020, doi: 10.1109/ACCESS.2020.2980363.

[5] C. Wolff, “Intrapulse Modulation and Pulse Compression,” radar tutorial eu, https://www.radartutorial.eu (accessed Jun. 7, 2023).

[6] J. K. Kayani and A. J. Hashmi, "Comparative study of Non-Coherent Pulse Compression and Non-Coherent Pulse integration techniques for radars," *2013 14th International Radar Symposium (IRS)*, Dresden, Germany, 2013, pp. 696-701.

[7] M. Deng, H. Wu, Z. Cheng, J. Wang and Z. He, "Matched Filtering Performance Analysis for Massive MIMO Radar with One-Bit Quantization," *2023 IEEE Radar Conference (RadarConf23)*, San Antonio, TX, USA, 2023, pp. 1-6, doi: 10.1109/RadarConf2351548.2023.10149768.

[8] S. Salemian, H. Keivani and O. Mahdiyar, "Comparison of radar pulse compression techniques," *2005 IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications*, Beijing, China, 2005, pp. 1076-1079 Vol. 2, doi: 10.1109/MAPE.2005.1618106.

[9] C. Brinegar, "Passive direction finding: combining amplitude and phase based methods," *Proceedings of the IEEE 2000 National Aerospace and Electronics Conference. NAECON 2000. Engineering Tomorrow (Cat. No.00CH37093)*, Dayton, OH, USA, 2000, pp. 78-84, doi: 10.1109/NAECON.2000.894895.

[10] R. Ardoino, “Passive direction finding [DF] techniques – amplitude comparison,” Emsopedia, https://www.emsopedia.org/entries/passive-direction-finding-df-techniques-amplitude-comparison/ (accessed Jun. 11, 2023).

[11] “Fast fourier transform,” Wikipedia, https://en.wikipedia.org/wiki/-Fast_Fourier_transform (accessed Aug. 11, 2023).

[12] O. Aasim, “Machine learning project 3: Predict salary using polynomial regression,” Medium, https://medium.com/analytics-vidhya/machine-learning-project-3-predict-salary-using-polynomial-regression-7024c7bace4f (accessed Jun. 11, 2023).

[13] D. J. Torrieri, "Statistical Theory of Passive Location Systems," in *IEEE Transactions on Aerospace and Electronic Systems*, vol. AES-20, no. 2, pp. 183-198, March 1984, doi: 10.1109/TAES.1984.310439.

[14] “X300/X310,” X300/X310 - Ettus Knowledge Base, https://kb.ettus.com/-X300/X310 (accessed Jun. 9, 2023).

[15] Ettus Research, “Ubx 10 mhz - 6 ghz RX/TX, 160 MHz BW,” Ettus Research, https://www.ettus.com/all-products/ubx160/ (accessed Jun. 11, 2023).

[16] “Log-periodic antenna,” Wikipedia, https://en.wikipedia.org/wiki/Log-periodic_antenna (accessed June. 11, 2023).

[17] 4G LTE log periodic antenna, https://www.alibaba.com/product-detail/Wholesale-4G-LTE-log-periodic-antenna_60156933321.html (accessed Jun. 11, 2023).

[18] “Antenna theory - parabolic reflector,” Tutorialspoint, https://www.tutorialspoint.com/antenna_theory/antenna_theory_parabolic_reflector.htm (accessed Jun. 11, 2023).

[19] WatElectronics, “Low noise amplifier : Circuit, working, Types & Its Applications,” WatElectronics.com, https://www.watelectronics.com/low-noise-amplifier/ (accessed Jul. 11, 2023).

[20] “Matlab,” Wikipedia, https://en.wikipedia.org/wiki/MATLAB (accessed Jul. 11, 2023).

[21] “Matlab Gui,” MATLAB & Simulink, https://www.mathworks.com/-discovery/matlab-gui.html (accessed Jun. 11, 2023).

[22] LabVIEW, https://labviewwiki.org/wiki/LabVIEW (accessed Jun. 11, 2023).

[23]. A. M. ALmassri, M. B. Abuitbel, W. Z. WanHasan, S. A. Ahmad and A. H. Sabry, "Real-time control for robotic hand application based on pressure sensor measurement," *2014 IEEE International Symposium on Robotics and Manufacturing Automation (ROMA)*, Kuala Lumpur, 2014, pp. 80-85, doi: 10.1109/ROMA.2014.7295866.

APPENDICES

Appendix – A

Code for Radar

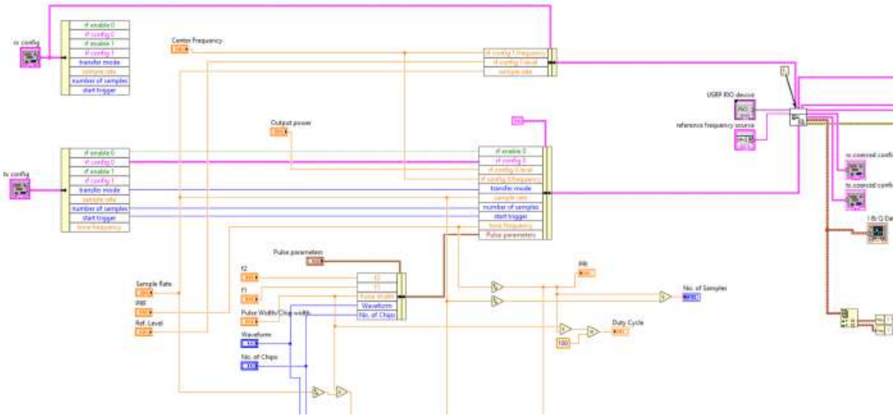
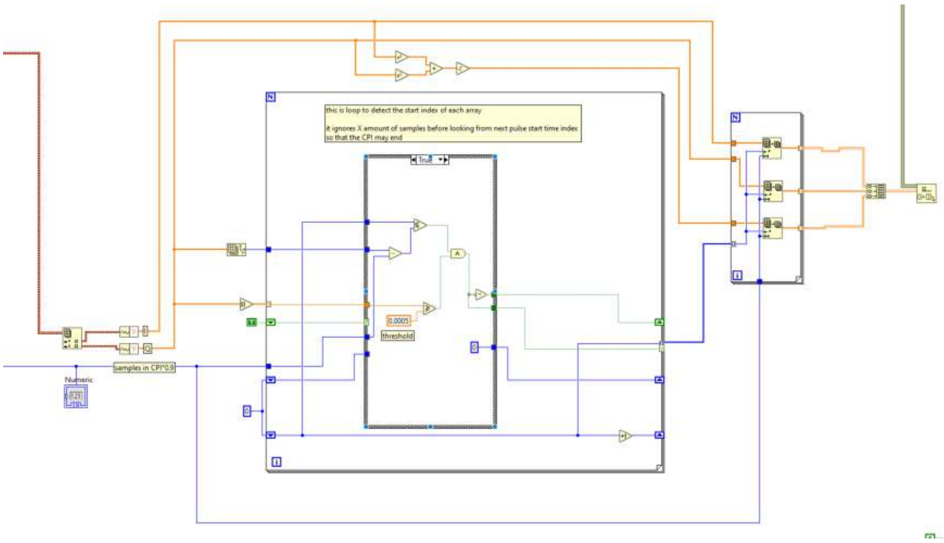


Figure 8-0-1: Setting Transmission Pulse Parameters.


this is loop to detect the start index of each array

it ignores X amount of samples before looking from next pulse start time index so that the CPI may end

Figure 8-0-2: Extracting PRI

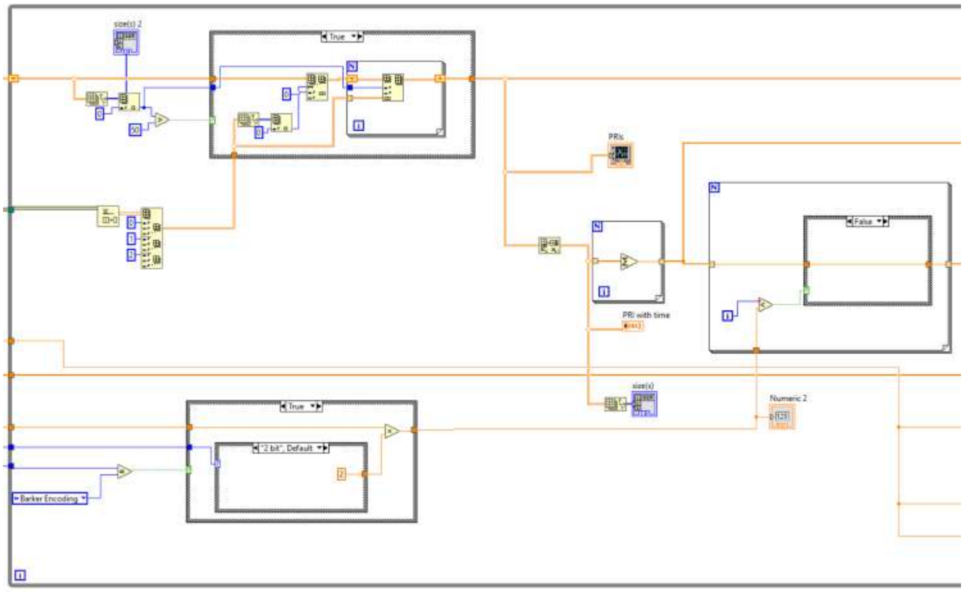


Figure 8-0-3:Pulse Integration

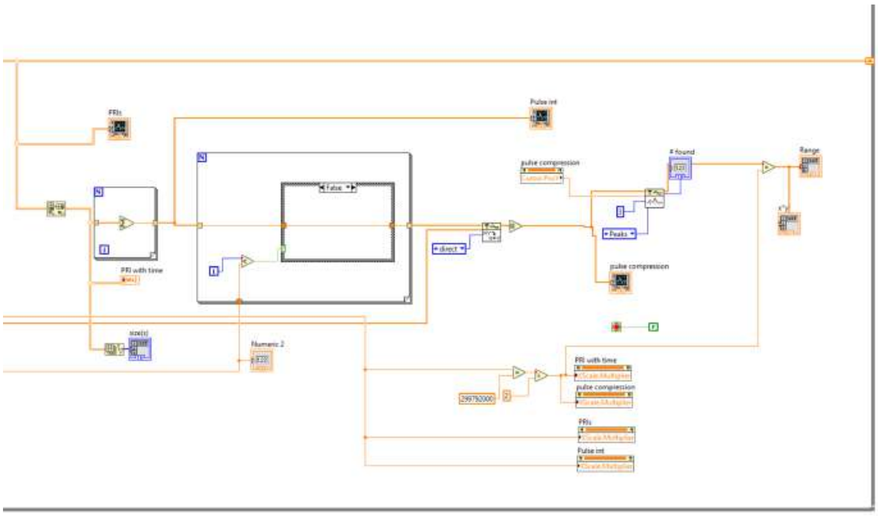


Figure 8-0-4: Pulse Compression

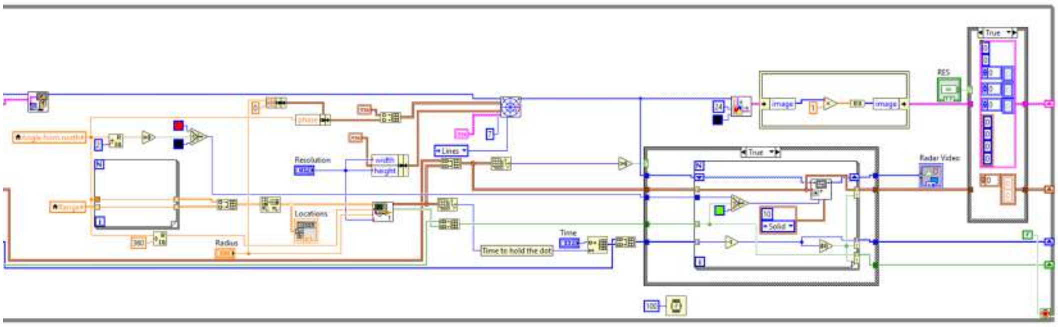


Figure 8-0-5: Displaying Target Detections

Appendix – B

Code for DF

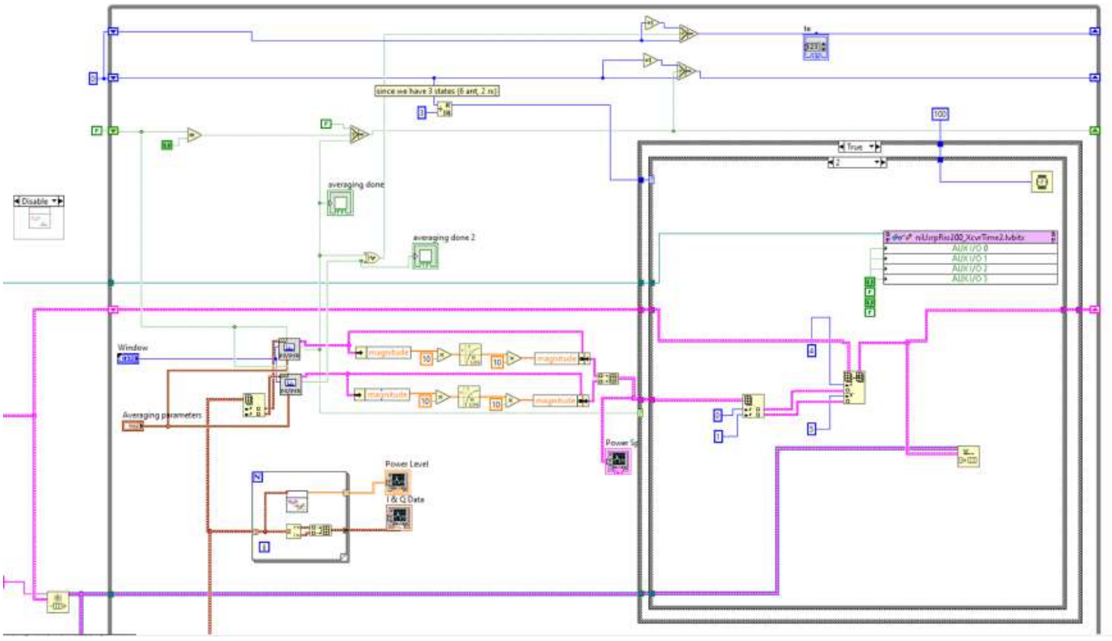


Figure 8-0-6: FFT Averaging and Switch Controls

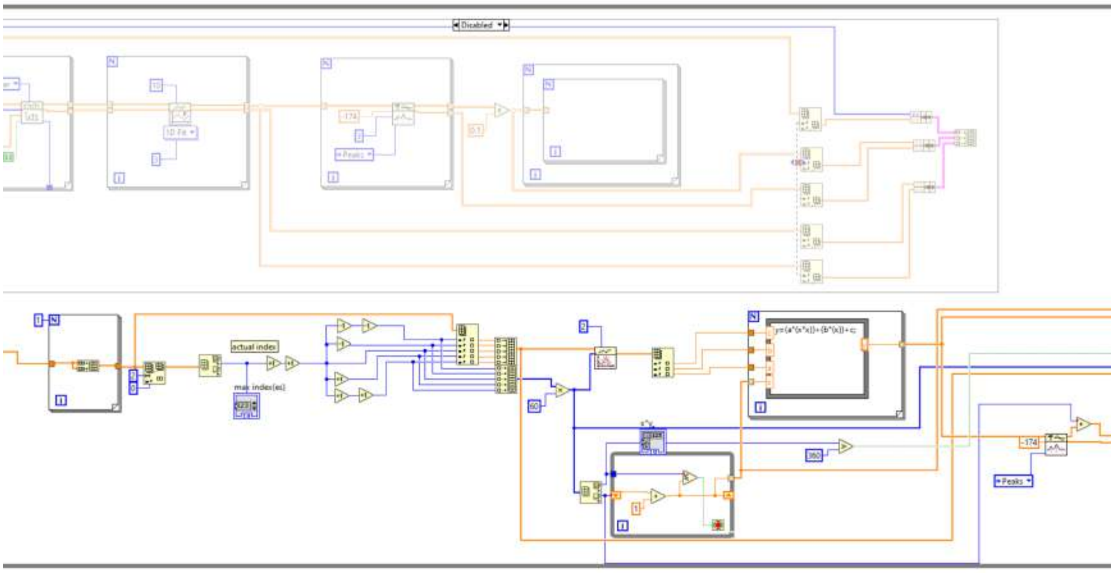


Figure 8-0-7: 2nd Order Polynomial Regression

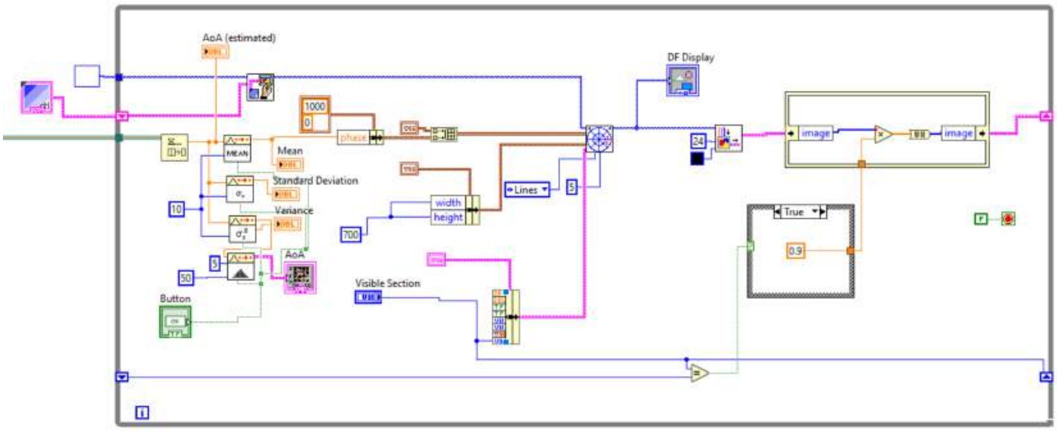
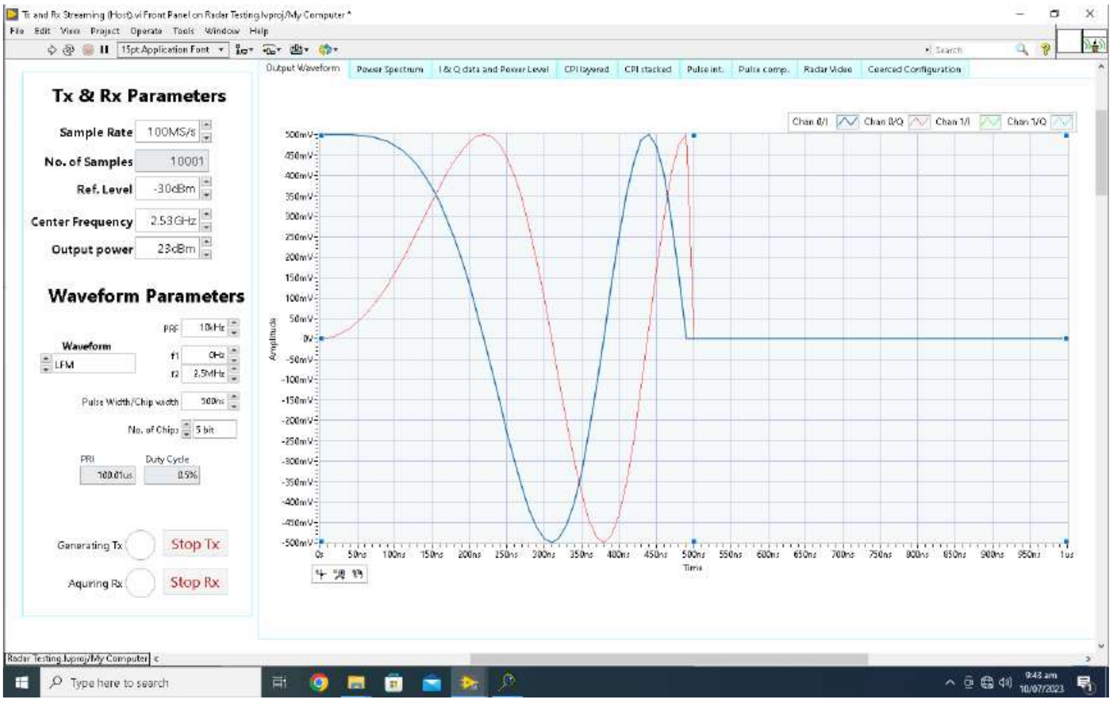


Figure 8-0-8: Displaying AOA Estimations

Appendix – C

LFM Results radar



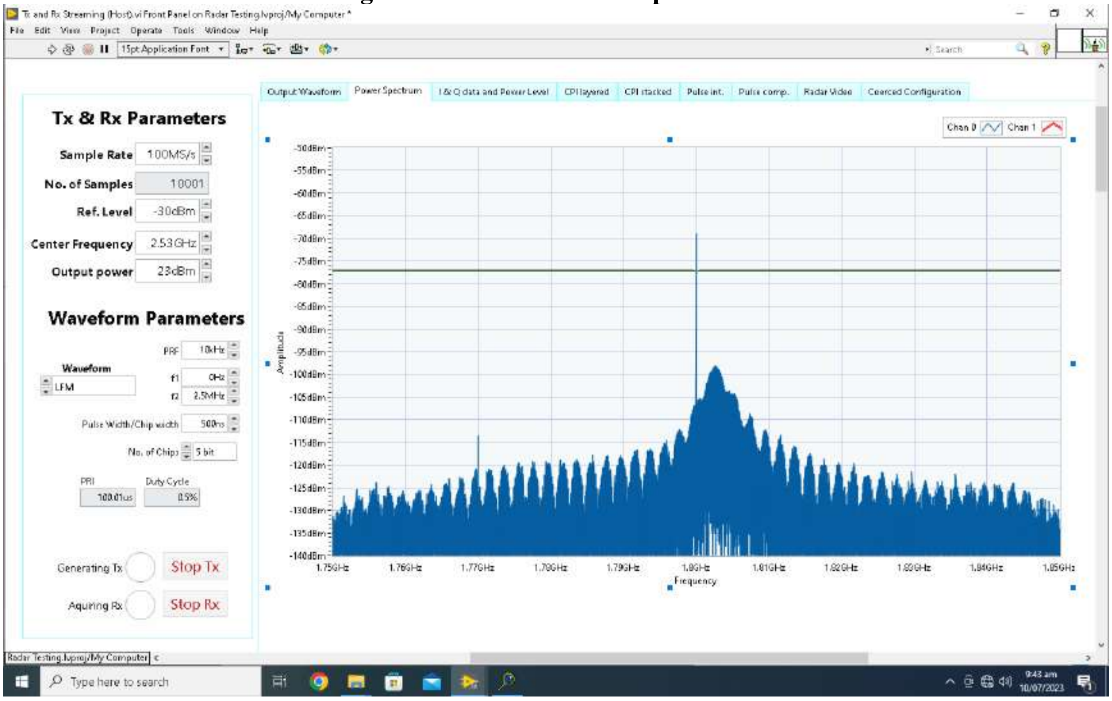
Tx & Rx Parameters

Sample Rate: 100MS/s
No. of Samples: 10001
Ref. Level: -30dBm
Center Frequency: 2.53GHz
Output power: 23dBm

Waveform Parameters

PRF: 10kHz
Waveform: LFM
f1: 0Hz
f2: 2.5MHz
Pulse Width/Chip width: 500ns
No. of Chips: 5 bit
PRI: 100.01us
Duty Cycle: 0.5%
Generating Tx
Aquiring Rx

Figure 8-0-9: Transmission pulse LFM



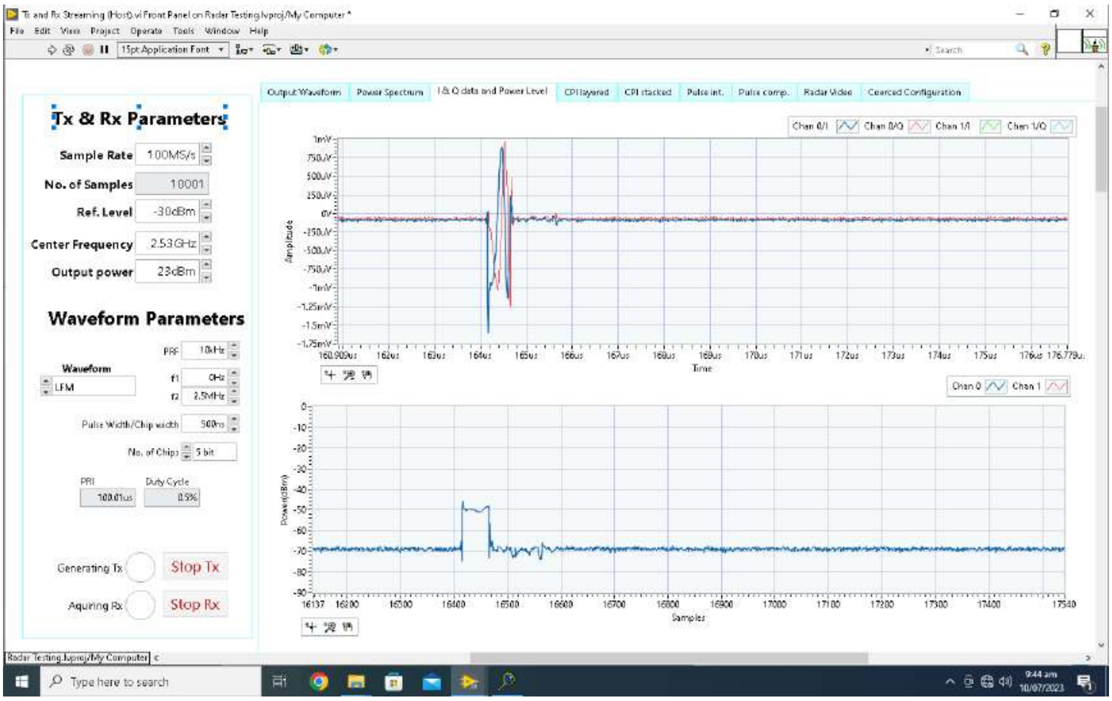
Tx & Rx Parameters

Sample Rate: 100MS/s
No. of Samples: 10001
Ref. Level: -30dBm
Center Frequency: 2.53GHz
Output power: 23dBm

Waveform Parameters

PRF: 10kHz
Waveform: LFM
f1: 0Hz
f2: 2.5MHz
Pulse Width/Chip width: 500ns
No. of Chips: 5 bit
PRI: 100.01us
Duty Cycle: 0.5%
Generating Tx
Aquiring Rx

Figure 8-0-10: FFT of LFM



Tx & Rx Parameters

Sample Rate 100MS/s

No. of Samples 10001

Ref. Level -30dBm

Center Frequency 2.53GHz

Output power 23dBm

Waveform Parameters

PRF 10kHz

Waveform LFM

f1 0Hz

f2 2.5MHz

Pulse Width/Chip width 500ns

No. of Chips 5 bit

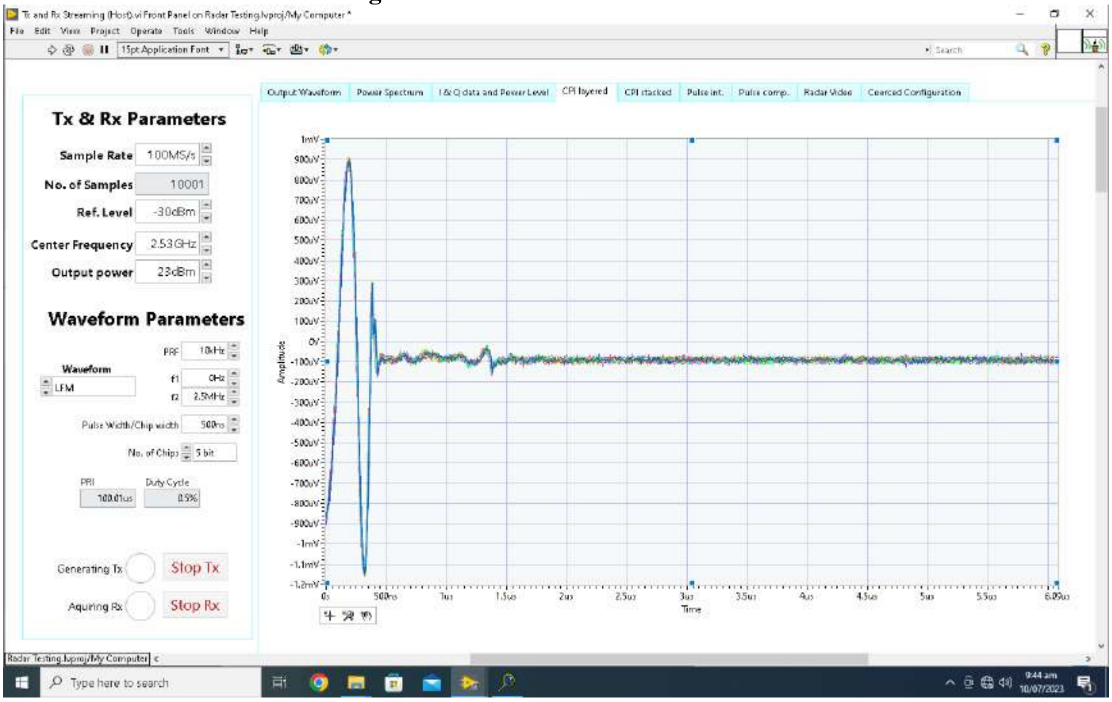
PRI 100.01us

Duty Cycle 0.5%

Generating Tx ○ Stop Tx

Aquiring Rx ○ Stop Rx

Figure 8-0-11: Returned PRI of LFM



Tx & Rx Parameters

Sample Rate 100MS/s

No. of Samples 10001

Ref. Level -30dBm

Center Frequency 2.53GHz

Output power 23dBm

Waveform Parameters

PRF 10kHz

Waveform LFM

f1 0Hz

f2 2.5MHz

Pulse Width/Chip width 500ns

No. of Chips 5 bit

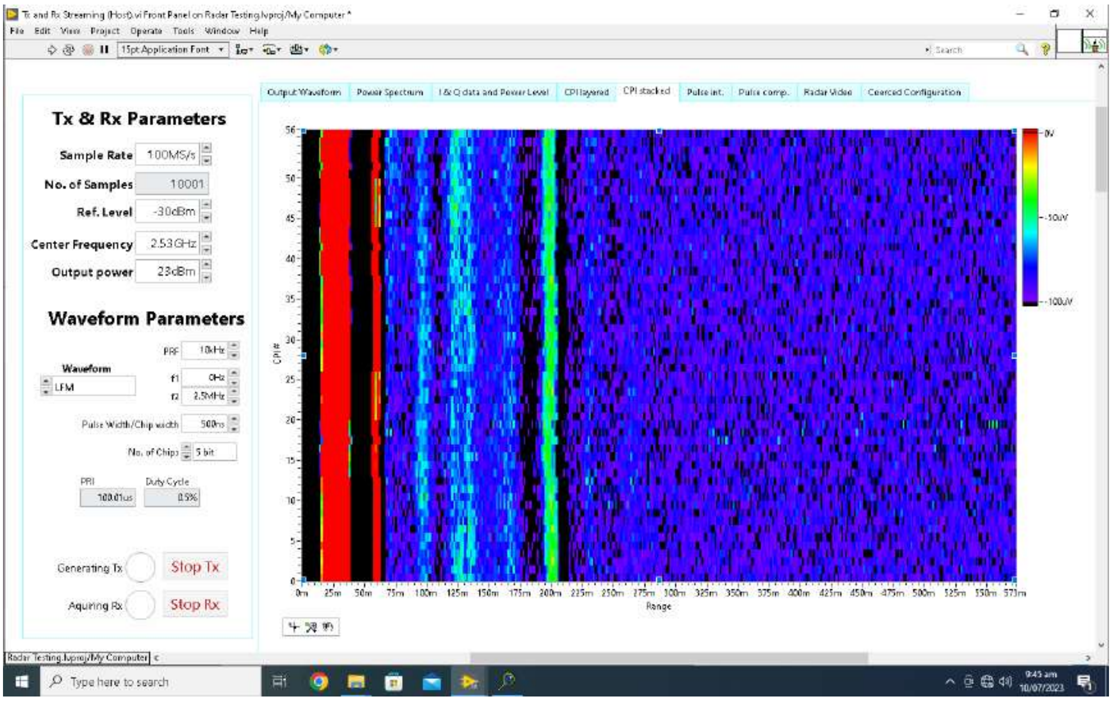
PRI 100.01us

Duty Cycle 0.5%

Generating Tx ○ Stop Tx

Aquiring Rx ○ Stop Rx

Figure 8-0-12: Stacking PRIs LFM



Tx & Rx Parameters

Sample Rate 100MS/s
No. of Samples 10001
Ref. Level -30dBm
Center Frequency 2.53GHz
Output power 23dBm

Waveform Parameters

PRF 10kHz
Waveform LFM
f1 0Hz
f2 2.5MHz
Pulse Width/Chip width 500ns
No. of Chips 5 bit
PRI 100.01us
Duty Cycle 0.5%

Generating Tx ○ Stop Tx
Aquiring Rx ○ Stop Rx

Figure 8-0-13: Stacking PRI in Respect to Time for LFM

Tx & Rx Parameters

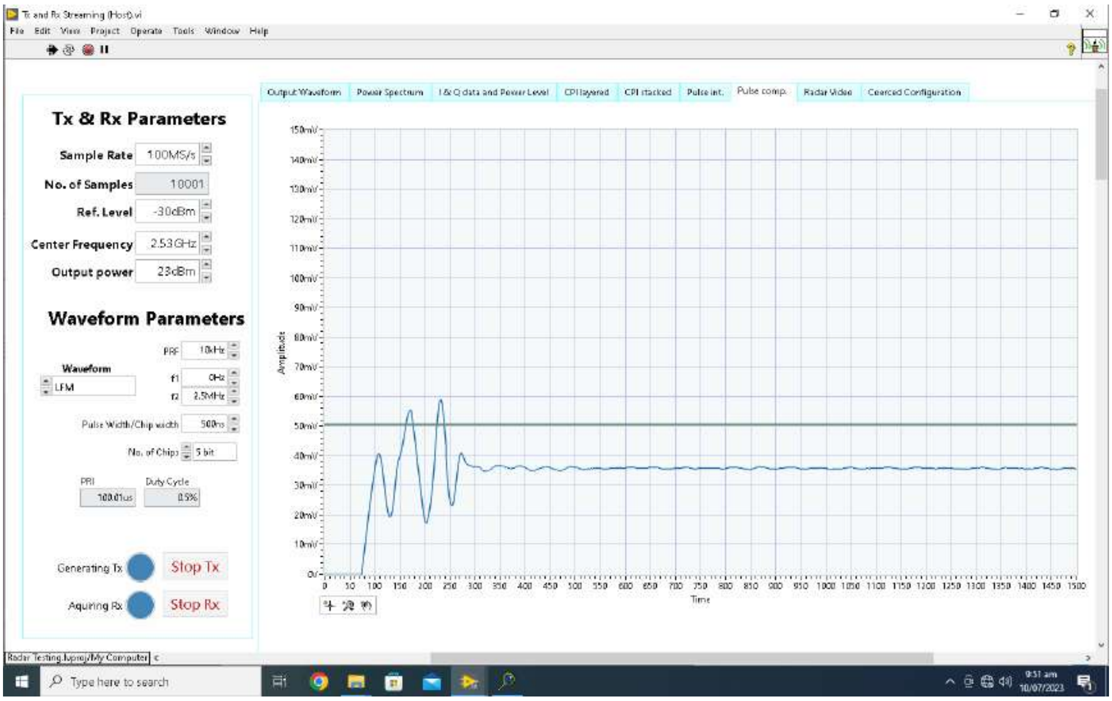
Sample Rate 100MS/s
No. of Samples 10001
Ref. Level -30dBm
Center Frequency 2.53GHz
Output power 23dBm

Waveform Parameters

PRF 10kHz
Waveform LFM
f1 0Hz
f2 2.5MHz
Pulse Width/Chip width 500ns
No. of Chips 5 bit
PRI 100.01us
Duty Cycle 0.5%

Generating Tx ○ Stop Tx
Aquiring Rx ○ Stop Rx

Figure 8-0-14: Pulse Integration for LFM



Tx and Rx Streaming (Host).vi

Tx & Rx Parameters

Sample Rate: 100MS/s

No. of Samples: 10001

Ref. Level: -30dBm

Center Frequency: 2.53GHz

Output power: 23dBm

Waveform Parameters

PRF: 10kHz

Waveform: LFM

f1: 0Hz

f2: 2.5MHz

Pulse Width/Chip width: 500ns

No. of Chips: 5 bit

PRI: 100.01us

Duty Cycle: 0.5%

Figure 8-0-15: Pulse Compression for LFM