Visvesvaraya Technological University, Belagavi.

A PROJECT REPORT
On

“ADVANCED SIGNAL PROCESSING FOR GROUND PENETRATING RADAR "

Project Report submitted in partial fulfillment of the requirement for the award of the degree of
Bachelor of Engineering
in
Electronics and Communication Engineering
For the academic year 2019-20
Submitted by

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CERTIFICATE

This is to Certify that the dissertation work **"Advanced Signal Processing for Ground Penetrating Radar"** carried out by Meghana. N, Namrata Sinha, Sandeep Elizha, V. Chaithanaya, USN: 1CR16EC082, 1CR16EC092, 1CR16EC148, 1CR16EC180, bonafide students of **CMRIT** in partial fulfillment for the award of **Bachelor of Engineering** in **Electronics and Communication Engineering** of the **Visvesvaraya Technological University, Belagavi,** during the academic year **2019-20**. It is certified that all corrections/suggestions indicated for internal assessment have been incorporated in the report deposited in the departmental library. The project report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said degree.

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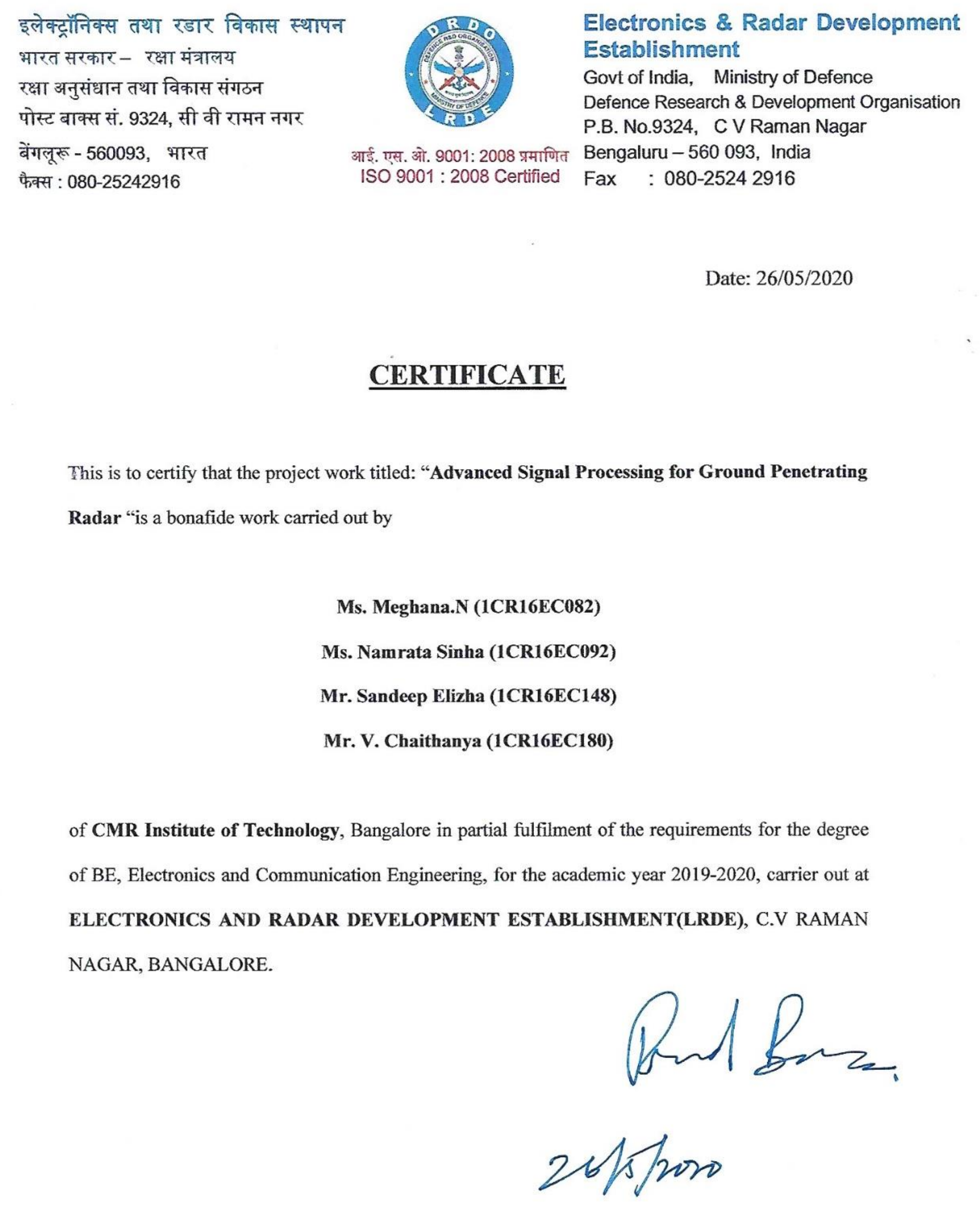
ORGANISATION CERTIFICATE



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ABSTRACT

Ground-penetrating radar (GPR) is a kind of high-frequency electromagnetic detection technology. It is mainly used to locate targets buried under the soil. In addition to the effective signals reflected from the subsurface objects or interfaces, the GPR signals in fieldwork also include noise and different clutters, such as antenna-coupled waves, ground clutters, and radio-frequency interference, which has similar wavelet spectral characteristics with the target signals. Clutter and noise seriously interfere with the target’s response signal. Noise when undergoes processing, its characteristics like probability density function, mean, variance will change and affect the performance of detection process. So, noise characteristics change need to be studied and better detection process has to be adapted for reducing false alarms. The noise characteristics after each stage of signal processing is estimated in signal processing stages using, pulse compression, moving target indicator, coherent integration and the final power is estimated.

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INTRODUCTION

1.1.About the Organization

Electronics and Radar Development Establishment (LRDE) is a laboratory of the Defence Research & Development Organization (DRDO). Located in C.V. Raman Nagar, Bangalore its primary function is research and development of Radars and related technologies. LRDE is sometimes mis-abbreviated as "ERDE". To distinguish between "Electrical" and "Electronic", the latter is abbreviated with the first letter of its Latin root (lektra). The same approach is used with for the DLRL. The LRDE is India's premier Radar design and development establishment and is deeply involved in Indian Radar efforts. Its primary production partners include Bharat Electronics Ltd. and various private firms like Mistral in Bangalore, Astra micro in Hyderabad and Data patterns in Chennai. The genealogy of LRDE originates from the Inspectorate of Scientific Stores created in 1939 at Rawalpindi. This was re-christened as TDE (Technical Development Establishment) in early 1946 and relocated in Dehradun. With electronic industrial complexes growing in the Bangalore outskirts, the Electronics part of TDE (I&E) branched off to settle in this seminal city in 1955. Coinciding with the promotion of DRDO (Defence Research and Development Organization), then TDE (E) was divided into Inspectorate of Electronics Equipment (ILE) and LRDE (Electronics RADAR Development and Establishment) on 01 Jan 1958 to meet the aspiration of Defense Services.

LRDE moved to the present location in 1986 to find place for expansion and growth. Born in the barracks of High Grounds in Jan 1958 as Electronic Research and Development Establishment, got the present name Electronics & Radar Development Establishment in Jun 1962. With the nucleus personnel, equipment and material inherited from parental TDE (E), initial emphasis was laid to undertake such tasks as investigation of defects in equipment or necessary modifications required to improve the performance of equipment covering the entire spectrum of defence electronics.

During the initial years, the necessity of redefining the objectives of establishment was appreciated to reorient & to undertake development of modern sophisticated and complicated radio, line communication, Radar, electrical, electro-medical equipment, devices, and their accessories with maximum indigenous content. With every passing year, efforts were concentrated in recruiting committed, qualified personnel and organizing the various divisions or departments, so as to function in a well- coordinated fashion for undertaking meaningful development of systems that could withstand the rigmarole of field acceptance. Early in life, LRDE visualized the scientific and logical guidelines for the systematic development of electronic equipment.

The roles of DRDO, User Agencies, the Inspection Authorities and Maintenance Authorities were orchestrated through DDPIL-64. LRDE played a major role in bringing out the modified DDPIL-69 which has withstood the test of time till date, albeit practical modifications or adaptations. Structured and partnership-oriented development processes were born in late sixties. The functional based Radar Divisions, the Engineering Service Divisions, in consonance with professional project management practices, came into existence during 1967-68. Digital electronics and embedded software became integral part of every equipment and system conceived and developed. And two low level Radars, Local Warning Radar (LOWARD) and Low Flying Target Detection Radar (LFDR) for Indian Army and Indian Air Force respectively, were the first indigenous Radars mooted for development using contemporary technologies like digital signal processing, digital display and Radar data processor. Later, they were renamed as INDRA-I and INDRA-II respectively. Modern Project Management processes, based on DDPIL Procedure were firmly established with balanced organizational mix.

LRDE scientists have been always ahead of their time. Phased Array design, Engineering of hardware and development of PCMs (pulse code modulation) for Multimode Radar paved the way to develop weapon control Radar Rajendra for Akash Weapon System. INDRA-I, INDRA-II with Pulse Compression and Rajendra Radars rolled out in this era of uncertainties and challenges. The unprecedented growth of LRDE during the second half of the Golden Jubilee period is due to multitude of enticing or compelling scenarios.

Areas of Work

Design and Development of Radar Systems for army based, Navy based, air force based by LRDE is as given below

a) Army:
    - Multifunction Phased Array Radar and 3D Surveillance Radar for Akash Missile Weapon System.
    - Low Level Light weight 2D Radar for mountainous terrain Air Defence.
    - 3D -Tactical Control Radar for Air Defence.
    - Short Range Battle Field Surveillance Radar.

- Weapon Locating Radar.
- Multi Mission Radar (MMR).
- FOPEN Radar.
- Through wall detection Radar.
- Ground Penetration Radar.

b) Air Force:

- Multifunction Phased Array Radar and 3D Surveillance Radar for Akash Missile Weapon System.
- Active Phased Array Radar for AEW&C.
- Low level 2D Air Defence Radar.
- 3D Low Level Light Weight Radar.
- 3D Medium Range Surveillance Radar for Air Defence (AD).
- 4D Active Array Medium Power Radar for AD role.
- Airborne Electronically Scanned Array Radar for Tejas Mark II.
- Ground Controlled interception.
- SAR for UAVs.

c) Navy:

- Maritime Patrol Radar for fixed and Rotary Wing Aircraft.
- Maritime Patrol Radar with RS and ISAR.
- 3D Medium Range Surveillance Radar for ASW Corvettes.
- Multifunction Phased Array Radar for Air Defence Ship.
- Maritime Patrol Airborne Radar for UAV.
- Coastal Surveillance Radar (CSR).

Products and Technologies for Civil Sectors

Terminal-based Air Traffic Control (ATC) Radars 3D Medium Surveillance Radar (3D CAR) can be upgraded with Radar Data Processing (RDP) for improved and efficient handling of large air traffic. The Radar Networking System can be used to link various ATC Radars to extend the air surveillance coverage to regulate civil air traffic. Transfer of Radar air pictures through digital data link of limited bandwidth (possible at output of RDP) will enable netting shore-based as well as offshore Radar installations for coastal air defense. Industrial Perimeter Surveillance Radar Light Weight Battery Powered Radar (BFSR - SR) for Surveillance of large industrial, defense and other installations to detect intruders up to the distance of 2 kms. The Radar can detect even a crawling man. Classification of targets such as Crawling man, walking man, Group of men walking, moving light vehicles is possible with Doppler Tone. Antennas Slotted Waveguide Array Solutions are available in X and Ku band for airborne and lad-based Radars. The antennas are rugged, compact and offer high radiation efficiency with high power handling capability. Microstrip Patch Array Antenna Solutions are available in X band for airborne and ground-based Radar. It is light-weight, low power and cost effective. Radar Data Processing (RDP) Technology RDP technology, using state-of-the-art processors (like Power PC) and very efficient algorithms, is established and available. The technology offers efficient solutions in automatic tracking of multiple targets, False alarm and clutter suppression, multi sensor data fusion, target classifications etc. Avalanche Victim Detector (AVD) AVD can be used by high altitude trekkers and mountaineers as life saving device in case of burial under avalanche or any other debris. The device can be used in the mining sector for limited burial depth.

1.2.Problem Objective

The novel detection method proposed here can eliminate false targets and enhance the target visibility in GPR data. However, the conventional time-domain method introduces false signals like clutters, when eliminating direct waves, and does not have good suppression of random noise. Different numerical models and real field GPR data were handled using the proposed method. Based on the power of fake signals introduced via different processes, qualitative and quantitative analyses are planned to be carried out. Also, a comparison is planned to analyze the newly proposed method functionality qualitatively and quantitatively to prove the designed concepts. Finally, the radar signal is reconstructed with improved target resolution.

This project addresses the problem of analyzing and improving the performance of GPR in detecting and characterizing objects in civil engineering infrastructures. Significant amount of works in this area has been attempted recently including detection of pipes, cables and reinforcement, locating subsurface cavities and fractures in bedrock, as well as ground water and moisture. This work tackles some of the issues, by developing and adapting a range of signal processing techniques from other disciplines into a comprehensive automated detection system that can be used effectively by untrained radar practitioners in site survey situations.

The objectives of the project are listed below.

1) Improvement of SNR
2) Enhancement of target information in the background of clutter and noise
3) design and implementation of simulated data for the comparison and evaluation against measured data in reducing the amount of clutter and unwanted signals presented in GPR data;
4) A comparative performance analysis.

1.3.Problem Statement

The most fundamental problem in radar is detection of an object or physical phenomenon. This requires determining whether the receiver output at a given time represents the echo from a reflecting object or only noise. Detection decisions are usually made by comparing the amplitude of the receiver output to a threshold which may be set a priority in the radar design or may be computed adaptively from the radar data. The problem associated in this radar project is to detect the required target and to remove unwanted noise along with the clutter which is making our original signal to disappear in the received echo signal. These problems are aimed to be solved in this project.

1.4.Problem Definition

When multiple targets are present in the radar field of view, additional considerations of resolution and side lobes arise in evaluating detection performance. For example, if two targets cannot be resolved by radar, they will be registered as a single object. If side lobes are high, the echo from one strongly reflecting target may mask the echo from a nearby but weaker target, so that again only one target is registered when two are present. The purpose of signal processing in radar is to improve the figures of merit. SNR can be improved by pulse integration. Resolution and SNR can be jointly improved by pulse compression and other waveform design techniques.

Radar receives the target echo along with the noise. Target detection is based on the threshold detection method where the target SNR is compared with the noise level (this includes system thermal noise and the external environmental noise). Selection of threshold for target detection is based on the acceptable probability of detection. Generally, threshold detection algorithms are sufficient for detection of single/multiple targets.

In some situations, clutters are formed around the target of interest. Clutters are also formed due to intentional or unintentional debris. Performance of detection algorithm degrades when the clutters are formed. The clutter occupies wide spectrum around the target spectrum. The spectral spread causes either increases in false alarm rate or masks the actual target detection due to rise in noise floor depending upon the characteristics of the clutter. The problem is to detect the real target in such scenarios. The scenarios may change from frame to frame and detection algorithm may need to have knowledge of target for proper detection.The main difficulty in radar detections is the presence of unknown parameters under each hypothesis, including environmental (clutter) parameters and target related parameters.

1.5.Development Process

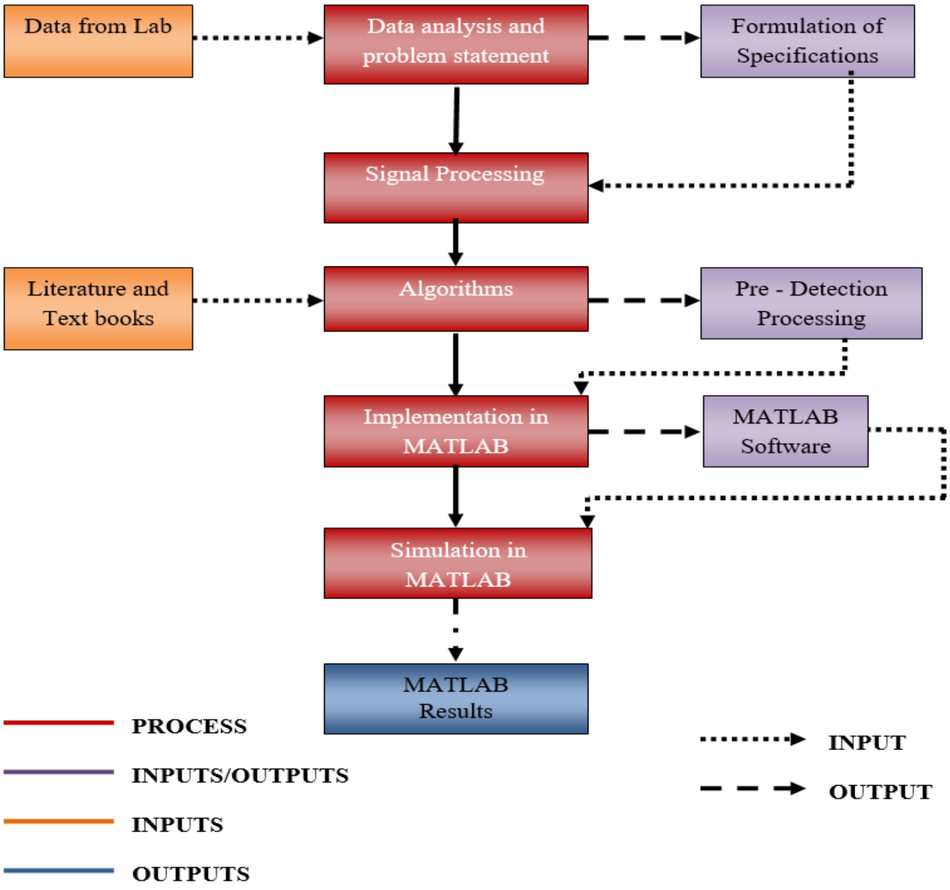

Fig 1.1 Development Process

Chapter 2

LITERATURE SURVEY

Literature survey is the most important step in software development process. Before developing the tool, it is necessary to determine the time factor, economy and company strength. Once these things are satisfied, then next steps are to determine which software can be used for developing the tool. Once the programmers start building the tool the programmers need lot of external support. This support can be obtained from senior programmers, from book or from websites. Before building the system, the above considerations are taken into account for developing the proposed system.Following references were reviewed in order to obtain details on the general concepts of Noise, Clutter, Detection, and corresponding algorithms of the project work. Fundamental concepts play a major role in setting a foundation to understand the theory behind any topic.

To do with the Algorithms: A book by Merill Skolnik "Introduction to Radar Systems [1], 2nd edition, McGraw Hill, 1980":

It was referred to know the basic concepts behind Radar. There has been continual development of new radar capabilities and continual improvements to the technology and practice of radar. This book helps in dealing with the detailed knowledge of the Radar basic which will help in the assessment of project specifications and learning for better future developments and completion of project. The radar clutter has been reorganized to include methods for the detection of targets in the presence of clutter. Generally, the design techniques necessary for the detection of targets in a clutter, background are considerably different from those necessary for detection in a noise background. Subsequent advances in digital technology, originally developed for applications other than radar, have allowed the practical implementation of the multiple delay-line cancelers and multiple pulse-repetition-frequency MTI radars indicated by the basic MTI theory. A book of this type which covers a wide variety of topics cannot be written in isolation.

To do with the software coding on MATLAB: Book by Stephen J. Chapman, "MATLAB programming for engineers [2]", was referred:

Engineering students use computer tools to perform complex tasks such as scientific calculations, data analysis, simulations, and visualization: all skills students will use again in upper level classes. MATLAB provides several built-in toolkits to help students accomplish these tasks, as well as an integrated development environment. It is an introduction to MATLAB as a technical programming language rather than an introduction to the MATLAB environment. It includes numerous pedagogical tools such as special boxes that highlight good programming practices, boxes that detail common pitfalls in MATLAB programming, and numerous programming exercises and examples. It also makes wide use of MATLAB's predefined functions that provide tested solutions and time saved in writing subroutines or functions. It teaches how to write clean, efficient, and documented programs using sound problem solving techniques.

Arya V.J1, Subha V2 1, "Matched Filtering Algorithm for Pulse Compression Radar [3]":

This paper is discussing the application of pulse compression radar to track launch vehicles, the stationary target as well as moving vehicle so as to check whether it had followed the predetermined path or not. Pulse Compression is one of the key steps in the signal processing of a radar system. Pulse compression technique is a method of achieving the benefits of short pulses while keeping the peak power within practical limits. This is a method of combining the high resolution capability of a short pulse with the high energy of a long pulse. This is achieved by modulating the transmitted pulse and then matching the received signal with the transmitted pulse. Matched filter is used as the pulse compression filter which provides high SNR at the output. Matched Filter is a time reversed and conjugated version of the received radar signal. There are several methods of pulse compression that have been used in the past, out of which most popular technique is Linear Frequency Modulation (LFM). This paper discussed the application of pulse compression radar to track launch vehicles, the stationary target as well as moving vehicle so as to check whether it had followed the predetermined path or not.

Mahmoud Gaballah, Motoyuki Sato,"A new approach to enhancement of ground penetrating radar target signals by pulse compression"[4]:

Ground penetrating radar (GPR) is an effective tool for detecting shallow subsurface targets. In many GPR applications, these targets are veiled by the strong waves reflected from the ground surface, so that we need to apply a signal processing technique to separate the target signal from such strong signals. A pulse-compression technique is used in this research to compress the signal width so that it can be separated out from the strong contaminated clutter signals. This work introduces a filter algorithm to carry out pulse compression for GPR data, using a Wiener filtering technique. The filter is applied to synthetic and field GPR data acquired over a buried pipe. The discrimination method uses both the reflected signal from the target and the strong ground surface reflection as a reference signal for pulse compression. For a pulse-compression filter, reference signal selection is an important issue, because as the signal width is compressed the noise level will blow up, especially if the signal-to-noise ratio of the reference signal is low. Analysis of the results obtained from simulated and field GPR data indicates a significant improvement in the GPR image, good discrimination between the target reflection and the ground surface reflection, and better performance with reliable separation between them.

“A Comparison of coherent and differentially coherent integration schemes for channels” [5], by Reinhold Haeb:

The aim of this paper is to present such a comparison for the frequency-nonselective Rayleigh channel. The common origin of the two detection schemes is revealed by viewing carrier recovery as estimation of the multiplicative channel distortion**.** This paper presents an overview and analysis of the regarding carrier recovery as the estimation of the distortion; we reveal the common basis of coherent and differentially coherent detection. In the differentially coherent receiver a very simple estimate of the distortion is used whereas the coherent receiver uses the optimal estimate. calculated using a single method of calculation for both detection schemes. The calculation takes into account non-perfect carrier recovery, cochannel interference, and diversity. The results allow a direct comparison of the two schemes and show that coherent detection is preferable in many realistic environments.

“An Analysis of Coherent Integration and Its Application to Signal Detection” [6], by K. S. MilleriI and R. I. Bernstein:

This paper presents an overview and analysis of the important characteristic of coherent integrators is that their effective bandwidth decreases as the integration time increases. If it is only known that a weak signal occurs somewhere in a given frequency range, then the number of integration channels required to cover the specified range increases as the amount of coherent integration is increased. However, each integration channel can independently cause a false alarm, although only the particular channel in which the signal appears can cause a true alarm. The question arises therefore whether it is profitable to lengthen the coherent integration period to increase the signal-to noise ratio when doing so requires an increase in the number of integration channels. This problem is investigated analytically. Numerical results appropriate for system design are presented as a series of graphs of missed-signal probability vs number of integration channels, with initial signal-to-noise ratio and over-all false alarm probability as parameters also included is a detailed analysis of statistical properties of ideal and approximate ideal coherent integrators.

“Detection, Estimation, and Modulation Theory” [7], by Harry L. Van Trees:

It was referred to understand the general concepts of Radar-Sonar Processing and Gaussian Signals in Noise, Neyman-Pearson criterion. Advances in computational capability have allowed the implementation of complex algorithms that were only of theoretical interest in the past. In many applications, algorithms can be implemented that reach the theoretical bounds. The books use continuous time processes but the transition to discrete time processes is straightforward. Integrals that were difficult to do analytically can be done easily in Matlab? The various detection and estimation algorithms can be simulated and their performance compared to the theoretical bounds.

“Radar Systems, Peak Detection and Tracking” [8], by Michael O. Kolawole:

It was referred to understand the general concepts of target detection in range, Fast Fourier transform, noise in Doppler processing, probability density function, decision theory, signal processing and matched filter. This book tells reader how radar works , how signal captured by radar receivers are processed, parametrized and present for tracking and how tracking algorithms are formulated. This book is written with keeping science and engineering in mind so that it becomes more useful for science and communication professionals and practicing electrical and electronics engineers.it is useful in understanding for radar system fundamentals principles, underlying technologies, architecture, design constraints and real-world applications. It tells about the receiver sensitivity, data acquisition or compression issue as well as application of radar. It explains how radar equations are developed recognizing the effect of environment on the conventional, lazer and secondary radar performance and detection of targets of variable radar cross sections and mobility.

“Fourier Transforms in Radar and Signal Processing” [9], by David Brand wood:

It was referred to understand the general concepts of fourier transform, inverse fourier transform, and different distribution functions. Fourier transforms are used widely, and are of particular value in the analysis of single functions and combinations of functions found in radar and signal processing. Still, many problems that could have been tackled by using Fourier transforms may have gone unsolved because they require integration that is difficult and tedious. Now you can solve many of these problems with the integration-free approach to carrying out Fourier transforms (and Fourier series) presented in this book. This book establishes a unified system that makes implicit the integration required for performing Fourier transforms on a wide variety of functions. It details how complex functions can be broken down to their constituent parts for analysis.

Chapter 3

INTRODUCTION TO RADAR SYSTEMS

3.1. Introduction

RADAR - Radio Detection and Ranging is a method of using electromagnetic waves to remote-sense the position, velocity, and identifying characteristics of targets. This is accomplished by illuminating volume of space with electromagnetic energy and sensing the energy reflected by objects in that space. The radar can classify the targets bases on the target kinematic parameters, ranges, signal strength, etc. Radar has wide range of application in various fields such as Military, Remote sensing, Air Traffic control, Law enforcement and Highway safety, Aircraft safety and navigation, Space and many other fields.

3.2. Principle of Radar

The basic principle of radar is that a transmitter generates an electromagnetic signal such as a short pulse of a sine wave that is radiated into space by an antenna. A portion of the transmitted energy is intercepted by the target and reradiated in many directions. The radiation directed back towards the radar is collected by the radar antenna, which delivers it to a receiver. There it is processed to detect the presence of the target and determine its location. A single antenna is usually used on time shared basis for both transmitting and receiving when the radar waveform is a repetitive series of pulses. The range to a target is found by measuring the time it takes for the radar signal to travel to the target and return to the radar.

When the target is in motion, there is a shift in the frequency of the echo signal due to the Doppler Effect. This frequency shift is proportional to the velocity of the target relative to the radar. The Doppler frequency shift is widely used in radar as the basis for separating desired moving targets from fixed clutter echoes reflected from the natural environment such as land, sea, or rain. Radar can also provide information about the nature of the target being observed.

The range to a target is determined by the time T_R it takes the radar signal to travel to the target and back. Electromagnetic energy in free space travels with the speed of light, which is c = 3 x 10^8 m/s. Thus the time for the signal to travel to a target located at a range R and return back to the radar is 2R/c.

The range to a target is then

$$R = \frac{cT_R}{2} \qquad \text{……………………….…………………….} \ (3.1)$$

The radar emits a periodic series of pulses, the period is denoted as the pulse repetition interval (PRI), and its inverse is the pulse repetition frequency (PRF). The PRF may range from a few hundred hertz to tens and sometimes a few hundreds of kilo hertz.

Pulse radars that extract the Doppler frequency shift are called either moving target indication (MTI) or pulse Doppler radars, depending on their particular values of pulse repetition frequency and duty cycle. MTI radar has a low PRF and a low duty cycle. A pulse Doppler radar has a high PRF and a high duty cycle. Almost all radars designed to detect aircraft use the Doppler frequency shift to reject the large unwanted echoes from stationary clutter.

Radars are used to detect the presence of a target and to determine its location. It refers to the use of radio waves to detect objects and determine the distance (range) to the object. The contraction implies that the quantity measured is range. While this is correct, modern Radars are also used to measure radial speed and direction. It turns out that by measuring these parameters one can perform reasonably accurate calculations of the x-y-z location and velocity of a target. In practice, the transmitted signal needs to be very large and the received signals are very small. Interfering signals can be very large and this can dwarf the desired signals.

The electronic principle on which Radar operates is very similar to the principle of sound-wave reflection. If you shout in the direction of a sound-reflecting object we will hear an echo. If we know the speed of sound in air, you can then estimate the distance and general direction of the object. The time required for an echo to return can be roughly converted to distance if the speed of sound is known. The radio-frequency (rf) energy is transmitted to and reflected from the reflecting object. A small portion of the reflected energy returns to the Radar set. This returned energy is called an ECHO, just as it is in sound terminology. Radar sets use the echo to determine the direction and distance of the reflecting object.

3.3.Design of Radar system

The following figure shows the operating principle of a primary Radar set. The Radar antenna illuminates the target with a microwave signal, which is then reflected and picked up by a receiving device. The electrical signal picked up by the receiving antenna is called echo or return. The Radar signal is generated by a powerful transmitter and received by a highly sensitive receiver

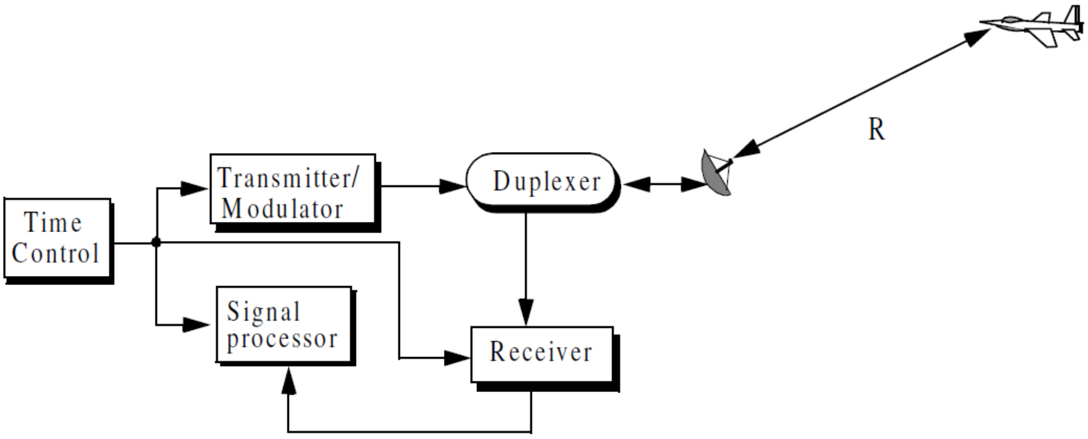

Fig 3.1. A simplified pulsed radar block diagram

All targets produce a diffuse reflection i.e. it is reflected in a wide number of directions. The reflected signal is also-called scattering. Backscatter is the term given to reflections in the opposite direction to the incident rays. Radar signals can be displayed on the traditional plan position indicator (PPI) or other more advanced Radar display systems. A PPI has a rotating vector with the Radar at the origin, which indicates the pointing direction of the antenna and hence the bearing of targets. The following are the main components of a basic radar system:

- Transmitter

  The Radar transmitter produces the short duration high-power rf pulses of energy that are into space by the antenna.
- Duplexer

  The duplexer alternately switches the antenna between the transmitter and receiver so that only one antenna need be used. This switching is necessary because the high-power pulses of the transmitter would destroy the receiver if energy were allowed to enter the receiver.
- Receiver

  The receivers amplify and demodulate the received RF-signals. The receiver provides video signals on the output.

- Antenna

  The Antenna transfers the transmitter energy to signals in space with the required distribution and efficiency. This process is applied in an identical way on reception.
- Threshold Decision:

  The output of the receiver is compared with a threshold to detect the presence of any object. If the output is below any threshold, the presence of noise is assumed.
- Duplexer:

  A duplexer allows the antenna to be used as a transmitter or a receiver. It can be a gaseous device that would produce a short circuit at the input to the receiver when transmitter is working.

3.4. Radar Parameters

When designing a Radar system, there are some important concepts that affect the system's performance. These are necessary to understand in order to create a Radar that will see the targets.

a) Radar Range

There exist hundreds of versions of the Radar range equation. Below is one of the more basic forms for a single antenna system (same antenna for both transmit and receive). The target is assumed to be in the center of the antenna beam. The maximum Radar detection range is;

$$R_{max} = \sqrt[4]{\frac{P_t \; G^2 \, \lambda^2 \, \sigma}{(4\pi)^3 \, P_{min}}} = \sqrt[4]{\frac{P_t \; G^2 \, c^2 \, \sigma}{{f_o}^2 \; (4\pi)^3 \; P_{min}}} \qquad \text{….. (3.2)}$$

where,

P_t = Transmit power

P_{min} = minimum detectable signal(power)

λ = transmit wavelength

σ = target Radar cross section

f_o = frequency (Hz)

G= Antenna Gain(ratio)

c = speed of light

The variables in the above equation are constant and Radar dependent except target RCS. Transmit power will be on the order of 1 mW (0 dBm) and antenna gain around 100 (20 dB) for an effective radiated power (ERP) of 100 mW (20 dBm). Minimum detectable signals are on the order of picowatts; RCS for an automobile might be on the order of 100 square meters.

b) Minimum detectable signal

Minimum detectable signal (P_{min}) depends on receiver bandwidth (B), noise figure (F), temperature (T), and required signal-to-noise ratio (S/N). A narrow bandwidth receiver will be more sensitive than a wider bandwidth receiver. Noise figure is a measure of how much noise a device (the receiver) contributes to a signal: the smaller the noise figure, the less noise the device contributes. Increasing temperature affects receiver sensitivity by increasing input noise.

$$\mathbf{P_{min} = k\ T\ B\ F\ (S/N)_{min}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.3)$$

P_{min}= Minimum Detectable Signal

k = Boltzmann's Constant =1.37 x 10^{-23} (Watt*sec/°Kelvin)

T = Temperature(°Kelvin)

B = Receiver Bandwidth (Hz)

F = Noise Factor(ratio) , Noise figure(dB)

$(S/N)_{min}$ = Minimum Signal to Noise Ratio

c) Signal Time

Most functions of a Radar set are time-dependent. Time synchronization between the transmitter and receiver of a Radar set is required for range measurement. Radar systems radiate each pulse during transmit time (or Pulse Width τ), wait for returning echoes during listening or rest time, and then radiate the next pulse. A so-called synchronizer coordinates the timing for range determination and supplies the synchronizing signals for the Radar. It sent simultaneously signals to the transmitter, which sends a new pulse, and to the indicator, and other associated circuits. The time between the beginning of one pulse and the start of the next pulse is called pulse-repetition time (PRT) and is equal to the reciprocal of PRF as follows:

$$PRT=1/PRF \qquad \ldots.. (3.4)$$

The Pulse Repetition Frequency (PRF) of the Radar system is the number of pulses that are transmitted per second. The frequency of pulse transmission affects the maximum range that can be displayed.

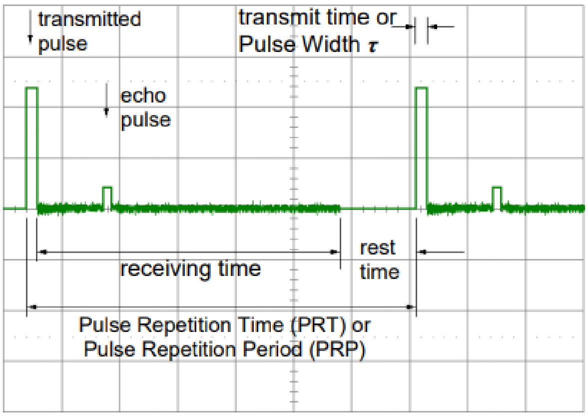

Fig 3.2: A typical RADAR timeline

d) Ranging

The distance of the aim is determined from the running time of the high-frequency transmitted signal and the propagation c0. The actual range of a target from the Radar is known as slant range. Slant range is the line of sight distance between the Radar and the object illuminated. While ground range is the horizontal distance between the emitter and its target and its calculation requires knowledge of the target's elevation. Since the waves travel to a target and back, the round-trip time is divided by two in order to obtain the time the wave took to reach the target. Therefore, the following formula arises for the slant range:

$$R = \frac{t_{delay} \cdot c_o}{2} \qquad \text{...... (3.5)}$$

where,

R is the slant range

t_{delay} is the time taken for the signal to travel to the target and return

c_o is the speed of light (approximately 3·108 m/s)

e) Maximum Unambiguous Range

The Radar receiver measures the time between the leading edges of the last transmitting pulse and the echo pulse. It is possible that an echo will be received from a long-range target after the transmission of a second transmitting pulse. The measurement process assumes that the pulse is associated with the second transmitted pulse and declares a much-reduced range for the target.

This is called range ambiguity and occurs where there are strong targets at a range in excess of the pulse repetition time. The pulse repetition time defines a maximum unambiguous range. To increase the value of the unambiguous range, it is necessary to increase the PRT, this means: to reduce the PRF. Echo signals arriving after the reception time are placed either into the

- transmit time where they remain unconsidered since the Radar equipment isn't ready to receive during this time, or
- into the following reception time where they lead to measuring failures (ambiguous returns).

The maximum unambiguous range for given Radar system can be determined by using the formula:

$$R_{unamb} = (PRT - \tau).\frac{c_o}{2} \qquad \text{..... (3.6)}$$

The pulse repetition time (PRT) of the Radar is important when determining the maximum range because target return-times that exceed the PRT of the Radar system appear at incorrect locations (ranges) on the Radar screen. Returns that appear at these incorrect ranges are referred as ambiguous returns or second time around (second-sweep) echoes. The pulse width τ in this equation indicates that the complete echo impulse must be received.

f) Range Resolution

The range resolution of a Radar tells how well a Radar can discriminate between targets that are close together. This is a critical parameter for a situation in which multiple targets may be near each other, or in order to get enough detail in an image. The range resolution is defined as:

$$\Delta R = \frac{c}{2\sqrt{\epsilon_r B}} \qquad \text{......... (3.7)}$$

where,

R is the minimum distance between targets,

c is the speed of light, and

B is the signal bandwidth.

In free space (air), the relative permittivity is one. The only parameter over which a designer has control to increase the range resolution is B, which is why bandwidth selection can be so important.

g) Radar Cross-Section

In order for a Radar to see an object, that object must reflect energy back to the Radar. Typically, an object is called a scatterer, because it scatters energy in all directions when hit by a Radar signals. The scatter that returns to the Radar is called backscatter. The size, shape, and orientation of an object are all factors that affect how much backscatter returns to the Radar, and therefore, the Radar cross-section (RCS) of a target. According to Skolnik, RCS is "the projected area of a metal sphere which would return the same echo signal as the target had the sphere been substituted for the target,". Formally, it is defined as:

$$\sigma = \lim_{R\to\infty} 4\pi R^2 \frac{|E_s|^2}{|E_0|^2}, \qquad \ldots\ldots. (3.8)$$

where,

Es is the electric field strength of the scattered wave at the Radar, and

E0 is the electric field strength of the transmitted wave.

There is much to study on the subject of identifying objects based on their RCS signatures because they can vary significantly. For example, materials will affect how much backscatter returns to the Radar. Metals and dielectrics will reflect energy, whereas there actually exist Radar-absorbing materials that will soak up most of the received energy and scatter very little, if anything at all. Shape also heavily influences RCS. Sharp edges and large objects tend to have a larger RCS signature than rounded surfaces or small objects. Simple objects will have a correspondingly simple RCS, but complex objects usually have wildly varying RCS signatures.

h) Signal-to-Noise Ratio

One important variation of the Radar equation is to find the signal-to-noise ratio (SNR). This is useful if the system has a particular SNR requirement. SNR affects how detectable a target is; if the returned signal is obscured by noise, it will not be detected. It is the ratio of the received signal power to the system noise power. Given the noise power and receive power, these can be put together to find an expression for the SNR:

$$SNR = \frac{P_r}{P_N} = \frac{P_t G_t G_r \sigma \lambda^2 F_t^2 F_r^2}{(4\pi)^3 R^4 k T_s B_n}.$$

…… (3.10)

3.5. Classification of Radars

There are basically two types of RADAR systems, namely:

(a) Primary RADAR

(b) Secondary Radar

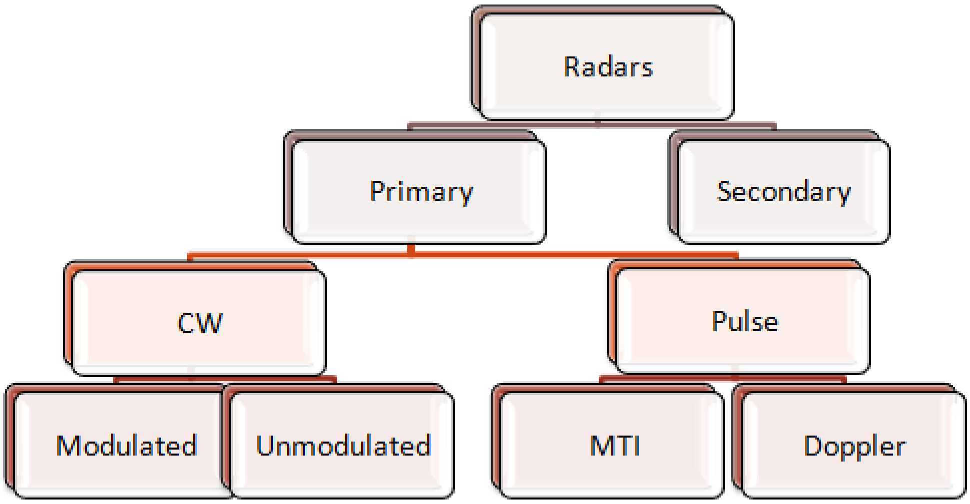

Fig 3.3: Classification of Radars

a) Primary Radar

Primary RADAR is also known as Primary surveillance RADAR (PSR). The transmitter radiates signal in all the direction, of which has a minimum ratio proportion of energy signal gets reflected back from the target to the receiver Several advantages of Primary RADAR are that it can operate independently of the target and does not require any co-operation by the target under surveillance. It is used by military purpose for detection of aircraft or ships. The disadvantages of Primary RADAR are; it needs high power to be radiated from the transmitter to ensure the return of signal from the target. Since, only minimum portion of signal get reflected back to the receiver, reflected signal may be disrupted by noise and signal attenuation from various factors. It cannot provide lot of information about the target, such as size and location with precise accuracy.

Primary Radar can de further divided into 2 groups:

(i) Pulsed Radar

Pulse Radar sets transmit a high-frequency impulse signal of high power. After this impulse signal, a longer break follows in which the echoes can be received, before a new transmitted signal is sent out. Direction, distance and sometimes if necessary, the height or altitude of the target can be determined from the measured antenna position and propagation time of the pulse-signal. These classically Radar sets transmit a very short pulse with an extremely high pulse-power. Pulse Radars can be classified into the following two types based on the type of the target it detects.

- Basic Pulse Radar
- Moving Target Indication Radar

This type of RADAR radiates the repetitive series of short duration rectangular pulses. There are two types of pulse RADARs. They are RADAR with Moving Target Indication (MTI) and RADAR with Pulse Doppler. Both uses Doppler frequency shift that deals with received signal to locate the target with moving motion. Example: Long range air surveillance RADAR, weather RADAR, test range RADAR, etc.

Ground Penetrating Radar is also a kind of Pulsed radar. The Ground penetrating radar (GPR) utilizes propagating electromagnetic (EM) waves that respond to changes in the electromagnetic properties of the shallow subsurface. The propagation velocity of EM waves in pulses, which is the principal controlling factor on the generation of reflections, is determined by the relative permittivity contrast between the background material and the target.

(ii) Continuous Wave Radar

A simple CW Radar can detect targets, measure their radial velocity, and determine the direction of arrival of the received signal. However, a more complicated waveform is required for finding the range of the target. It professes transmission and reception of continuous sine wave at the same time. It employs Doppler frequency shift for detecting moving targets. It can we further divided into two categories namely: Unmodulated Continuous Wave Radar and Frequency Modulated Continuous Wave Radar.

1) Unmodulated Continuous Wave Radar:

The Radar, which operates with continuous signal (wave) for detecting non-stationary targets is called Unmodulated Continuous Wave Radar . It is also called CW Doppler Radar. This Radar requires two Antennas. Of these two antennas, one Antenna is used for transmitting the signal and the other Antenna is used for receiving the signal. It measures only the speed of the target but not the distance of the target from the Radar.

2) Frequency-modulated Continuous-wave (FM-CW) Radar

If the frequency of a CW Radar is continually changed with time, the frequency of the echo signal will differ from that transmitted and the difference will be proportional to the range of the target. Accordingly, measuring the difference between the transmitted and received frequencies gives the range to the target. In such a frequency-modulated continuous-wave Radar, the frequency is generally changed in a linear fashion, so that there is an up-and-down alternation in frequency. The most common form of FM-CW Radar is the Radar altimeter used on aircraft or a satellite to determine their height above the surface of the Earth. Phase modulation, rather than frequency modulation, of the CW signal has also been used to obtain range measurement. The primary users of these Radars are the Army, Navy, Air Force, NASA, and USCG. CW Radar sets transmit a high-frequency signal continuously. The echo signal is received and processed permanently too. The transmitted signal of this equipment is constant in amplitude and frequency. This Radar is specialized in speed measuring. E.g. these Radars are used as speed gauges of the police.

b) Secondary RADAR:

Secondary RADAR is also known as SSR (Secondary Surveillance RADAR. It radiates a signal which is received by a compatible transponder. After successful retrieving of the signal, the target sends the useful information in the form of code. This information tells the receiver about the location, altitude, status and many other useful information of the target. The advantages of SSR over PSR are; the received signal is much more powerful and is not attenuated by any factors. The base station can get proper information about the aircraft/ships.

Chapter 4

GROUND PENETRATING RADAR

4.1 Introduction

Ground penetrating Radar (commonly called GPR) is a high-resolution electromagnetic device that is designed primarily to investigate the shallow subsurface of the earth, building materials, and roads and bridges. GPR is a time-dependent geophysical technique that can provide a 3-D pseudo image of the subsurface, including the fourth dimension of color, and can also provide accurate depth estimates for many common subsurface objects. Under favorable conditions, GPR can provide precise information concerning the nature of buried objects. It has also proven to be a tool that can be operated in boreholes to extend the range of investigations away from the boundary of the hole. GPR is a tool for indirectly looking at underground objects such as gravel and sand layers. The information or data received by GPR is like an x-ray or map of the underground. GPR uses electromagnetic waves like radio waves, which have a longer wavelength. The wavelength is the fundamental difference between the forms of electromagnetic energy.

4.2 Working Principle

GPR uses the principle of scattering of electromagnetic waves to locate buried objects. The basic principles and theory of operation for GPR have evolved through the disciplines of electrical engineering and seismic exploration, and practitioners of GPR tend to have backgrounds either in geophysical exploration or electrical engineering. The fundamental principle of operation is the same as that used to detect aircraft overhead, but with GPR that antennas are moved over the surface rather than rotating about a fixed point. This has led to the application of field operational principles that are analogous to the seismic reflection method. GPR is a method that is commonly used for environmental, engineering, archeological, and other shallow investigations.

GPR uses high-frequency (usually polarized) radio waves, usually in the range 10 MHz to 2.6 GHz. A GPR transmitter and antenna emits electromagnetic energy into the ground. When the energy encounters a buried object or a boundary between materials having different permittivity’s, it may be reflected or refracted or scattered back to the surface. A receiving antenna can then record the variations in the return signal. The principals involved are similar to seismology, except GPR methods implement electromagnetic energy rather than acoustic energy, and energy may be reflected at boundaries where subsurface electrical properties change rather than subsurface mechanical properties as is the case with seismic energy. The transmit and receive antennas are moved independently in the fixed mode of operation. This allows more flexibility of field operation than when the transmit and receive antennas are contained in a single box. For example, different polarization components can be recorded easily when the transmit and receive antennas are separate.

The resulting measurements that are recorded during the period of time that the receiver is turned on is called a trace. The idealized trace for this simple case consists of a direct pulse, and a single reflection from the layer. In the moving mode of operation, a Radar wave is transmitted, received and recorded each time that the antenna has been moved a fixed distance across the surface of the ground, or material, that is being investigated.

4.3 Block Diagram of a Typical GPR System

They are all comprised of five main components

1) Control Unit,
2) Transmitter,
3) Receiver,
4) Antennas, and
5) Interface, Data Storage, and Display Module.

The control unit receives the survey parameters from the interface and generates the timing signals for the transmitter and receiver. It also receives the data from the receiver and does the initial processing before sending it to the storage device. In some systems the interface, data storage, display and control unit are all incorporated into one unit. In other systems, the control unit is separate and a laptop or palmtop computer is employed to enter the survey parameters, store the data, and provide real-time data display. On the command of the control unit, the transmitter generates the electromagnetic pulse that is emitted through an antenna connected to it. The transmitter/antenna pair determine the center frequency and bandwidth of the signal that is sent into the ground. An antenna identical to that attached to the transmitter is attached to the receiver. This antenna intercepts reflected energy and sends it to the receiver where it is amplified, digitized and sent to the control unit. The time versus received energy graph is called a trace. Data are collected at frequent intervals along a profile, such that the traces can be plotted side by side, creating a pseudo-section through the ground. In higher frequency system (e.g., greater than approximately 300 MHz) the antennas can be shielded from unwanted externally generated electromagnetic (EM) energy. If the antennas are shielded, standard wire data cables can be used to connect the transmitter and receiver to the control unit

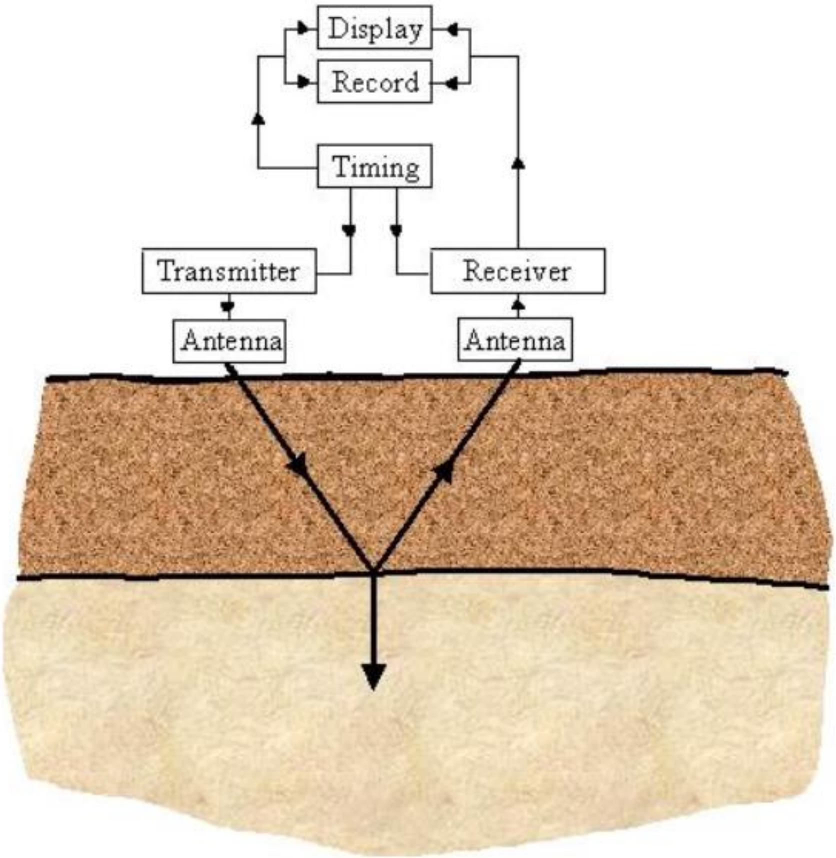

Fig 4.1: A typical GPR system

4.4 Applications

GPR has many applications in a number of fields.

a) Archaeology

Ground penetrating Radar survey is one method used in archaeological geophysics. GPR can be used to detect and map subsurface archaeological artifacts, features, and patterning. GPR depth slices showing a crypt in a historic cemetery. These Plainview maps show subsurface structures at different depths. Sixty lines of data – individually representing vertical profiles – were collected and assembled as a 3-dimensional data array that can be horizontally "sliced" at different depths.)

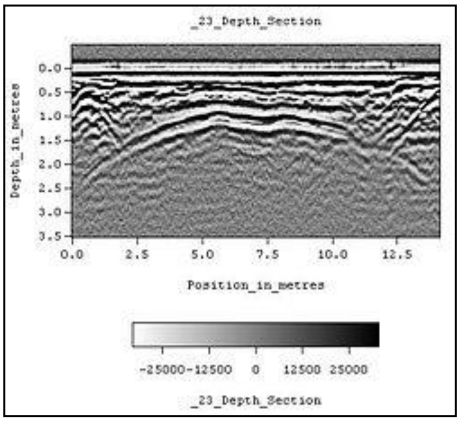

Fig 4.2: GPR Depth section

GPR depth section (profile) showing a single line of data from the survey of the historic crypt shown above. The domed roof of the crypt can be seen between 1 and 2.5 meters below surface. The concept of Radar is familiar to most people. With ground penetrating Radar, the Radar signal – an electromagnetic pulse – is directed into the ground. Subsurface objects and stratigraphy (layering) will cause reflections that are picked up by a receiver. The travel time of the reflected signal indicates the depth. Data may be plotted as profiles, as planview maps isolating specific depths, or as three-dimensional models.

GPR can be a powerful tool in favorable conditions (uniform sandy soils are ideal). Like other geophysical methods used in archaeology (and unlike excavation) it can locate artifacts and map features without any risk of damaging them. Among methods used in archaeological geophysics, it is unique both in its ability to detect some small objects at relatively great depths, and in its ability to distinguish the depth of anomaly sources.

b) Military

Military applications of ground-penetrating Radar include detection of unexploded ordnance and detecting tunnels. In military applications and other common GPR applications, practitioners often use GPR in conjunction with other available geophysical techniques such as electrical resistivity and electromagnetic induction methods.

c) Vehicle localization

A recent novel approach to vehicle localization using prior map-based images from ground penetrating Radar has been demonstrated. Termed "Localizing Ground Penetrating Radar" (LGPR), centimeter level accuracies at speeds up to 60 mph have been demonstrated.

4.5 Clutter

Clutter in general refers to cover or fill (something) with an untidy collection of things. Radar clutter may be defined as unwanted signals in a search Radar. Clutter is a term used to describe any object that may generate unwanted radar returns that may interfere with normal radar operations. Parasitic returns that enter the radar through the antenna’s main lobe are called main lobe clutter; otherwise they are called side lobe clutter. Clutter can be classified in two main categories: surface clutter and airborne or volume clutter. Surface clutter includes trees, vegetation, ground terrain, man-made structures, and sea surface (sea clutter). Land clutter is a more serious limitation than sea clutter.

Clutter can be fluctuating or non-fluctuating. Ground clutter is generally non-fluctuating in nature because the physical features are normally static. On the other hand, weather clutter is mobile under the influence of wind and is generally considered fluctuating in nature. Clutter can be defined as homogeneous if the density of all the returns is uniform. Most of the surface and volume clutter are analyzed on this basis, however, in practice, this simplification does not hold good in all cases. Non-homogeneous clutter is non-uniform clutter where the amplitude of the clutter varies significantly from cell to cell. Typically, non-homogeneous clutter is generated by tall buildings in built up areas.

Volume clutter normally has large extent (size) and includes chaff, rain, birds, and insects. Chaff consists of a large number of small dipole reflectors that have large RCS values. It is released by hostile aircraft or missiles as a means of ECM in an attempt to confuse the defense. Surface clutter changes from one area to another, while volume clutter may be more predictable.

Clutter echoes are random and have thermal noise-like characteristics because the individual clutter components (scatterer) have random phases and amplitudes. In many cases, the clutter signal level is much higher than the receiver noise level.

Thus, the radar’s ability to detect targets embedded in high clutter background depends on the Signal-to-Clutter Ratio (SCR) rather than the SNR.

White noise normally introduces the same amount of noise power across all radar range bins, while clutter power may vary within a single range bin. And since clutter returns are target like echoes, the only way a radar can distinguish target returns from clutter echoes is based on the target RCS σt, and the anticipated clutter RCS σ_c (via clutter map). Clutter RCS can be defined as the equivalent radar cross section attributed to reflections from a clutter area, Ac .The average clutter RCS is given by:

$$\sigma_c = \sigma° A_c \qquad \text{…………………………. (4.1)}$$

The term that describes the constructive/destructive interference of the electromagnetic waves diffracted from an object (target or clutter) is called the propagation factor. Since target and clutter returns have different angles of arrival (different propagation factors), we can define the SCR as:

$$SCR = \frac{\sigma_t {F_t}^2 {F_r}^2}{\sigma_c {F_r}^2} \qquad \text{……….............................. (4.2)}$$

where, Fc the clutter propagation factor,
Ft and Fr are, respectively, the transmit and receive propagation factors for the target.
In many cases Ft= Fr.

4.5.1 Types of Clutters

a) Surface clutter

Surface clutter includes both land and sea clutter, and is often called area clutter. Area clutter manifests itself in airborne radars in the look-down mode. It is also a major concern for ground-based radars when searching for targets at low grazing angles. Three factors affect the amount of clutter in the radar beam. They are the grazing angle, surface roughness, and the radar wavelength. Typically, the clutter scattering coefficient $\sigma 0$ is larger for smaller wavelengths.The low grazing angle region extends from zero to about the critical angle. The critical angle is defined by Rayleigh as the angle below which a surface is considered to be smooth, and above which a surface is considered to be rough. Ground or sea returns are typical surface clutter. Returns from geographical land masses are generally stationary; however, the effect of wind on trees etc… means that the target can introduce a Doppler shift to the radar return. This Doppler shift is an important method of removing unwanted signals in the signal processing part of a radar system. Clutter returned from the sea generally also has movement associated with the waves. Doppler shift can be calculated by

$$\Delta\lambda / \lambda 0 = V/C, \qquad \text{………….(4.3)}$$

where,

$\Delta\lambda$ is the shift in wavelength.

$\lambda 0$ is the wavelength of source not moving/ stationary source.

V is velocity of source-line of site.

C is speed of light.

Doppler shift can be either Red-shift (a shift of frequency to a lower wavelength, away from the observer) or Blue-shift (a shift of frequency to a higher wavelength, towards the observer). The power received from the clutter is given by

$$C = P_t G A_e \sigma_c / [(4\Pi)^2 R^2] \qquad \text{…………………………..(4.4)}$$

where, Pt is the transmitter power

G is gain of Antenna

A_e is antenna effective aperture

R is Range

σ_c is clutter cross-section.

The power received by the radar from a scatterer A_c within is given by the radar equation as

$$S_t = \frac{P_t G^2 \lambda^2 \sigma_t}{(4\Pi)^3 R^4} \qquad \text{………… (4.5)}$$

The SCR for area clutter is given by

$$(SCR)_{AC} = \frac{2\sigma_t \cos \psi\, g}{\sigma^{\circ} \theta_{3dB} R C \tau} \qquad \text{………….. (4.6)}$$

Radar Equation for Area Clutter - Ground Based Radar

The received power from clutter is also calculated using Eq. (6.9). However, in this case the clutter RCS σ_c is computed differently. It is

$$\sigma_c = \sigma_{MBc} + \sigma_{SLc} \qquad \text{…………….(4.7)}$$

where σ_{MBc} is the main beam clutter RCS and

σ_{SLc} is the sidelobe clutter RCS, as illustrated in Fig.

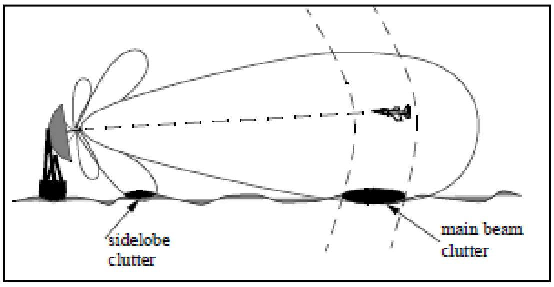

Fig. 4.3 Geometry of ground-based radar clutter

In order to calculate the total clutter RCS, one must first compute the corresponding clutter areas for both the main beam and the side lobes. For this purpose, consider the geometry shown in Fig. 4.6 The angles $\theta_A\ and\ \theta_E$ represent the antenna 3-dB azimuth and elevation beam widths, respectively. The radar height (from the ground to the phase center of the antenna) is denoted by h_r , while the target height is denoted by h_l . The radar slant range is , and its ground projection R_g is . The range resolution isΔR and its ground projection is ΔR_{g} . The main beam clutter area is denoted byA_{MBc} and the sidelobe clutter area is denoted by A_{SLc}.

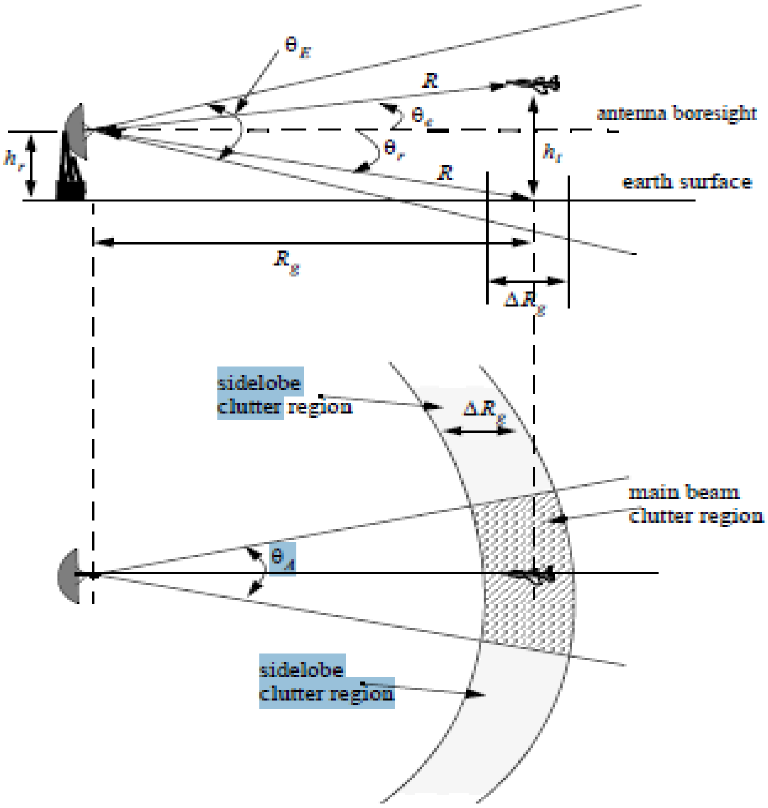

Fig 4.4 Clutter geometry for ground-based radar.

b) Volume Clutter

Volume clutter has large extents and includes rain (weather), chaff, birds, and insects. The volume clutter coefficient is normally expressed in squared meters (RCS per resolution volume).Birds, insects, and other flying particles are often referred to as angel clutter or biological clutter.

As mentioned earlier, chaff is used as an ECM technique by hostile forces. It consists of a large number of dipole reflectors with large RCS values. Historically, chaff was made of aluminum foil; however, in recent years most chaff is made of the more rigid fiberglass with conductive coating. The maximum chaff RCS occurs when the dipole length L is one half the radar wavelength.

Weather or rain clutter is easier to suppress than chaff, since rain droplets can be viewed as perfect small spheres. We can use the Rayleigh approximation of a perfect sphere to estimate the rain droplets. RCS. The Rayleigh approximation, without regard to the propagation medium index of refraction is:

$$\sigma = 9\pi r^2 (\mathrm{kr})^4 \qquad r \ll \lambda \text{……….}(4.8)$$

c) Sea Clutter

Sea Clutter are disturbing radar-echoes of sea wave crests. This clutter gets also a Doppler-speed by the wind. This means, the scenario, moves away i.e. changes with time, while for ground clutter, it stays the same. Therefore, in practice, Sea-Clutter is very difficult to control without some loss in detection. Sea-Clutter can be seen here in the below picture, the wind comes from about 3100(NO) or from the opposite direction. (Unfortunately, whether the Doppler frequency is positive or negative cannot be recognized on the PPI-Scope. But this region, in which the radial speed of the waves is very small, is cleaned by the MTI system very clearly.

Marine radars face the problems of sea clutter when detecting the surface ships, low-flying aircraft, icebergs, and other small surface objects. The sea clutter is highly dependent on the ocean state, radar grazing angle, wind velocity, and direction. Furthermore, sea echoes generally appear to have sea spikes, which will decrease the target detection performance, especially for the targets of low speed and low RCS. What's worse, when the grazing angle of marine radar is lower than 3◦ and the lengths of targets to be detected are smaller than 30 m, such as growlers, buoys, and small boats, especially the height of these targets are also low, the detection problem will be very difficult. The targets detection in sea clutter at the condition mentioned above is very important, because the primary purpose of marine radar is early warning targets, then to track or recognize them. Traditionally, sea clutter has been modeled as a stochastic process, and many models have been developed with employing different statistical distributions. One those model sone method is Constant False Alarm Rate (CFAR) algorithm, which can obtain satisfactory detection performance for surface targets with large RCS. Based on these To describe sea clutter characteristics, chaotic process seems to be also an important approach.

One of the most extensively used model for sea clutter is the compound K-distribution model. The compound *K*-distribution sea clutter model is not only a good fit to observed amplitude statistics over a wide range of conditions, but also allows the temporal and spatial correlation characteristics to be accurately modelled. The modelling of pulse-to-pulse correlation characteristics is very important for accurate performance prediction when pulse-to-pulse integration is used. The use of the compound *K*-distribution model not only gives more accurate results than models based on amplitude distribution alone, but also gives a new insight to the detection characteristics of different radar detection radar detection systems over a wide range of sea conditions.

4.5.2 Clutter Spectrum

The power spectrum of stationary clutter (zero Doppler) can be represented by a delta function. However, clutter is not always stationary; it actually exhibits some Doppler frequency spread because of wind speed and motion of the radar scanning antenna. In general, the clutter spectrum is concentrated around $f = 0$ and integer multiples of the radar PRF f_r , and may exhibit some small spreading.

The clutter power spectrum can be written as the sum of fixed (stationary) and random (due to frequency spreading) components. For most cases, the random component is Gaussian. If we denote the fixed to the random power ratio by W^2 , then we can write the clutter spectrum as

$$s_e(\omega) = \overline{\sigma_0}\left(\frac{W^2}{1+W^2}\right)\delta(\omega_0) + \frac{\overline{\sigma_0}}{(1+W^2)\sqrt{2\pi\sigma_\omega^2}} \exp\left(-\frac{(\omega-w_0)^2}{2\sigma_\omega^2}\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4.9)$$

where, $\omega_0 = 2\pi f_0$ is the radar operating frequency in radians per second,

σ_ω is the rms frequency spread component, and

$\overline{\sigma_0}$ is the Weibull parameter.

The first term of the right-hand side of Eq. (4.14) represents the PSD for stationary clutter, while the second term accounts for the frequency spreading. Nevertheless, since most of the clutter power is concentrated around zero Doppler with some spreading (typically less than 100 Hz), it is customary to model clutter using a Gaussian-shaped power spectrum (which is easier to analyze than Eq. (4.14)). More precisely,

$$S_0(\omega) = \frac{p_c}{\sqrt{2\pi\sigma_\omega^2}}\exp(-\frac{(\omega-w_0)^2}{2\sigma_\omega^2})\ldots \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.10)$$

where, p_c is the total clutter power;

$\sigma_\omega^2$and $\omega_0$were defined earlier.

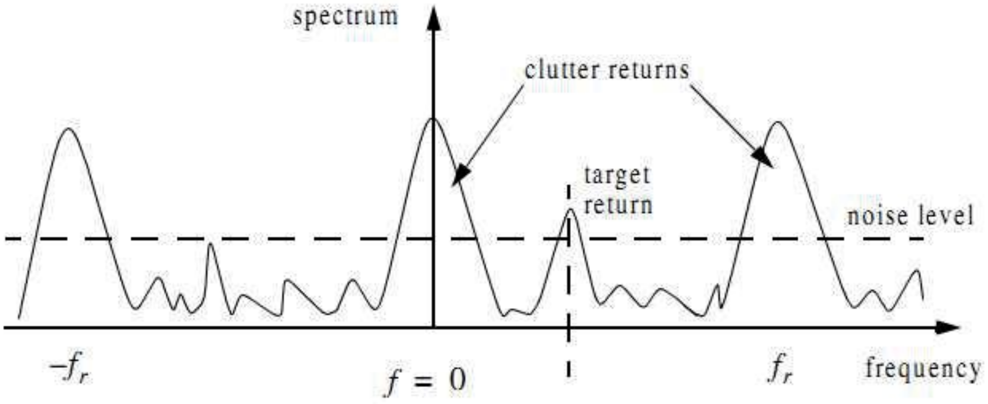

Fig 4.5 Typical radar return PSD when clutter and target are present

Fig. 4.5 shows a typical PSD sketch of radar returns when both target and clutter are present. Note that the clutter power is concentrated around DC and integer multiples of the PRF.

4.5.3 Clutter behaviour based on soil Properties

Ground-penetrating radar (GPR) has been used for surveys of geological structures and is becoming a more common tool for a variety of near-surface applications, including landmine detection, civil engineering, environmental studies, and agriculture. In these applications, measurements are usually obtained at a smaller scale, and higher resolution and higher sensitivity are required compared to the traditional large-scale applications of GPR such as geological survey and groundwater monitoring.

With high frequencies, GPR becomes more sensitive to the heterogeneity of soils surrounding targets, resulting in unwanted scattering of electromagnetic waves from heterogeneous soils called Clutter, which appears in the data.

The amount of clutter depends on the heterogeneity of soil.
Figure 4.9 shows an example of clutter in different degrees of soil heterogeneities.

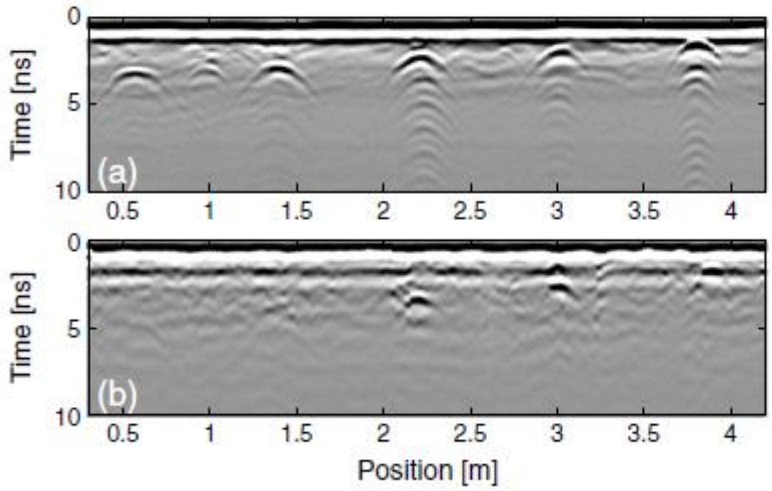

Fig 4.6 Examples of GPR vertical profiles in (a) homogeneous sand and (b) heterogeneous humus soil

All targets can easily be recognized by their hyperbolic signatures in homogeneous soil . However, in heterogeneous soil (Figure 4.9 b), their signatures were obscured by clutter, and reflections were weak because of scattering loss, which makes the targets difficult to detect. Soil heterogeneity is often characterized by two parameters, correlation length and variability, and scattered power is related to these parameters. Since the relationship is not a simple function, it is difficult to assess a soil type or to compare different types of soils for GPR measurement in terms of these parameters. However, direct assessment and comparison are possible in terms of scattered power.Which is similar to the concept of radar cross section (RCS), and the modeling aims to provide the RCS of soils. The soils may cause significant influence on the GPR performance in target detection if the RCS is high, meaning a large part of transmitted electromagnetic waves are scattered by soils, which may disturb target signature.

4.5.4 GPR Clutter modeling

The modeling technique aims to provide the amount of clutter caused by heterogeneous soils and observed on GPR profiles. Therefore, the heterogeneity of soils must be taken into account in the modeling. The heterogeneity for GPR may be determined from the spatial distribution of dielectric permittivity, because permittivity is the most influencing parameter on the reflectivity of electromagnetic waves in most soil types. Soil permittivity can be measured by time domain reflectometry (TDR) at various locations, and its heterogeneity can be quantified by geostatistical analysis from the spatial distribution of permittivity. For a 1-D permittivity distribution ϵ(x) measured by TDR, the semi variogram γ(h) is given by

$$\gamma(h)=\frac{1}{2N}\sum_{i=1}^{N_h}[\varepsilon(x_i+h)-\varepsilon(x_i)]\verb|^|2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4.11)$$

where, h is the lag distance between two data points,
ϵ(xi + h) and ϵ(xi), and
Nh is the number of data pairs with a constant lag distance h from all data points.

Often, the semi variance γ(h) increases with the lag distance h up to a certain value, after which it becomes constant, as shown in the example below. For the lag distance h, the semi variance γ(h) that becomes constant is referred to as the sill C; the corresponding h is called the range a. The range indicates the mean distance at which a data pair no longer correlates and thus is equivalent to correlation length and characteristic length.

A simple modeling that calculates clutter power takes into account of the statistical properties of permittivity distribution of soil. The model may need further verifications, for example, to assess the lower and higher-frequency limitations of the model because the amount of the interference between heterogeneous parts of soils is expected to change depending on frequency. The scattering caused by soil heterogeneity in the case of high-frequency GPR measurements is in the Mie scattering region. Which is different from the assumption of the Rayleigh approximation that is commonly used to describe scattering from soils, which is seen in conventional lower-frequency GPR investigations.

Clutter power can be calculated depending on the variability and correlation length of soil permittivity, which allows us to investigate the factors most influential to clutter. As a result, variability is generally more influential than correlation length; however, the influence of correlation length becomes greater when it is at multiples of wavelength.

Therefore, to evaluate soil heterogeneity for GPR measurements, correlation length must be considered in addition to variability. This makes it difficult to directly compare different types of soils, because these two properties are not in a simple relationship. Instead, the modeled clutter power allows us to compare and evaluate soils with different heterogeneities, which is the same concept as RCS.

4.5.6 Conclusion

The task of target detection is very demanding and requires the radar to dynamically adapt to the local environment in order to obtain the best possible detection sensitivity. Over the area, the clutter characteristics observed by the radar will be continuously changing as a function of range and look direction. These characteristics will vary in a manner dependent on the prevailing conditions, the radar characteristics and the viewing geometry. In practice, the radar must cope with a very wide dynamic range of signal amplitude, with amplitude statistics varying from those of thermal noise to very spiky sea clutter and land. Continuous adaptation to this environment is required as a function of range and bearing. The dynamic behavior of the radar as it adapts in this way is often a much more relevant measure of performance than more traditional static measures such as detection range. Clutter can be more harmful than receiver noise in limiting the ability of a radar to detect targets. It is far more difficult to characterize clutter than to characterize receiver noise.

4.6 NOISE

Noise is an unwanted disturbance in an electrical signal. Noise generated by electronic devices varies greatly as it is produced by several different effects. Noise is, however, typically distinguished from interference, for example in the signal-to-noise ratio (SNR), signal-to-interference ratio (SIR) and signal-to-noise plus interference ratio (SNIR) measures.

Noise is also typically distinguished from distortion, which is an unwanted systematic alteration of the signal waveform by the communication equipment, for example in signal-to-noise and distortion ratio (SINAD) and total harmonic distortion plus noise (THD+N) measures. Electrical and RF noise comes in many forms. It can be generated in many ways and noise can affect electronic and radio frequency, RF circuits and systems.

As noise is random by nature, it is not possible to eliminate its effects. Once it has entered a system it cannot be removed, it can only be reduced in some instances by filtering, although this may affect the wanted signal.

4.7 TYPES OF NOISE

Electronic or radio frequency, RF noise can be generated in a number of ways by different mechanisms. Accordingly, RF noise can be categorized according to the way it is generated. Different types of noise are generated by different devices and different processes. The types of can be classified as:

a) Avalanche Noise:

Avalanche breakdown occurs in semiconductors where a very high potential gradient exists. When this occurs electrons rapidly gain momentum and may hit the crystal lattice through which they travel with such energy that they can dislodge other charge carriers creating electron-hole pairs. In turn these carriers are accelerated and may similarly hit the lattice and dislodge further carriers. This process can lead to an avalanche of new carriers, and the breakdown of the pn- junction.The way that breakdown occurs results in a very uneven or ragged current flow. This means that high levels of noise - avalanche noise are generated.

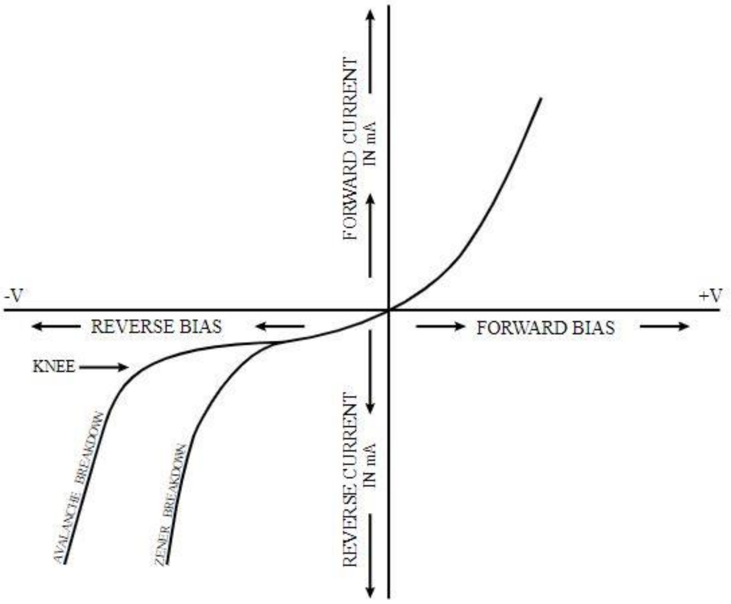

Fig 4.7 Avalanche noise

b) Flicker Noise:

Flicker noise is also known as 1/f noise in view of the fact that its power density decreases with increasing frequency or increasing offset from a signal. It follows a 1/f characteristic, having what is termed as pink noise spectrum. Flicker noise occurs in

almost all electronic devices, and it has a variety of different causes, although these are usually related to the flow of direct current. It is important in many areas of electronics and it is particularly important within oscillators used as RF sources. For RF oscillators overall noise performance is important, and 1/f noise forms one element of this.

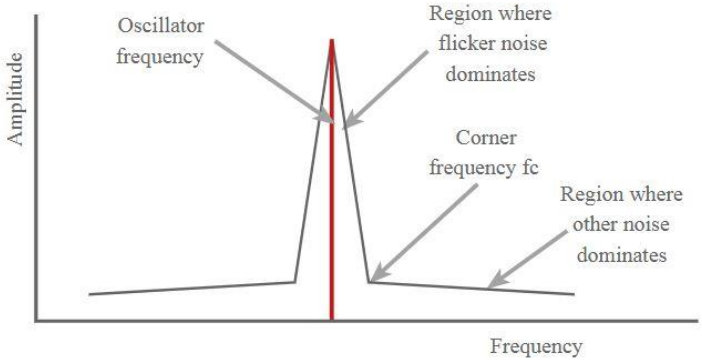

Fig 4.8. Flicker noise

c) Phase Noise

Phase noise is a form of RF noise that is visible on radio frequency, and other signals. It appears in the form of phase jitter or perturbations on the signal. These manifests themselves as sidebands that spread out either side of the signal or carrier. Phase noise can affect a signal or system in a variety of ways. One major area is when phase modulation is used to carry digital information. Phase noise can degrade the bit error rate, as the noise can disrupt the phase changes that indicate the state of the data to be transmitted.

d) Thermal Noise

Thermal noise is generated as a result of thermal agitation of the charge carriers which are typically electrons within an electrical conductor. This thermal noise actually occurs regardless of the applied voltage because the charge carriers vibrate as a result of the temperature. This vibration is dependent upon the temperature - the higher the temperature, the higher the agitation and hence the thermal noise level. Therefore, the only ways to reduce the thermal noise content are to reduce the temperature of operation, or reduce the value of the resistors in the circuit. Thermal noise, like other forms of noise is random in nature. It is not possible to predict the waveform and therefore it is not possible to reduce the effects by cancellation or other similar techniques.

e) Burst Noise

Burst noise consists of sudden step-like transitions between two or more levels. The burst noise steps may be as high as several hundred microvolts, at random and unpredictable times. Each shift in offset voltage or current can last for several milliseconds, and the intervals between pulses tend to be in the low audio range - typically less than about 100 Zobrist noise, or popcorn noise was an issue when the first operational amplifiers were introduced. It made a noise like cooking popcorn if sent to a loudspeaker - hence the name. The most common cause for this noise in ICs is believed to be the random trapping and release of charge carriers at thin film interfaces. Also defect sites in bulk semiconductor crystal can give rise to burst noise.

f) Shot Noise

Shot noise arises because current consists of a vast number of discrete charges, and is not a totally analogue phenomenon. The continuous flow of these discrete pulses gives rise to almost white noise. There is a cut-off frequency which is governed by the time it takes for the electron or other charge carrier to travel through the conductor. Unlike thermal noise, this noise is dependent upon the current flowing and has no relationship to the temperature at which the system is operating.

g) White Noise

White noise is the type of noise that affects all frequencies equally. It spreads up from zero frequency upwards with flat amplitude. It gains its name from the fact that white light contains all colours, and hence frequencies equally, and white noise contains all frequencies equally.

h) Pink Noise

The power density of pink noise falls with increasing frequency. It gains its name because red light is at the lower end of the light spectrum - its power density is biased towards lower frequencies. The spectral power density, compared with white noise, decreases by 3 dB per octave (density proportional to 1/*f*). For this reason, pink noise is often called "1/*f* noise.

i) Brownian Noise

Brownian noise, also called Brown noise, is noise with a power density which decreases 6 dB per octave with increasing frequency (frequency density proportional to 1/ *f2*) over a frequency range excluding zero (DC).Brownian noise can be generated with temporal integration of white noise. "Brown" noise is not named for a power spectrum that suggests the color brown; rather, the name derives from Brownian motion.

j) Blue Noise

Blue noise, which is sometimes considered high-frequency white noise, is a noise color with a spectral density that is proportional to its frequency. This means that the power and energy of the signal increases as frequency increases. Another distinguishing characteristic of blue noise is that each successive octave increases by three decibels.
Blue noise is used for dithering, a process where noise is added to a track to smooth out the sound and lessen the audibility of distortions

k) Violet Noise

Violet noise is also called purple noise. Violet noise's power density increases 6 dB per octave with increasing frequency (density proportional to *f* 2) over a finite frequency range. It is also known as differentiated white noise, due to its being the result of the differentiation of a white noise signal.

Chapter 5

SYSTEM REQUIREMENTS SPECIFICATION

5.1. Hardware requirements

Component	**Requirement**
Processor	64-bit, Intel-core™, 2.5 GHz minimum per core
RAM	16 GB for developer and evaluation use
Hard disk	50 GB for installation of MATLAB For use, we need additional free disk space for day-to-day operations. Add two times as much free space as you have RAM.

5.2. Software requirements

MS Word 2016:

Microsoft Word allows you to create professional-quality documents, reports, letters, and resumes. Unlike a plain text editor, Microsoft Word has features including spell check, grammar check, text and font formatting, HTML support, image support, advanced page layout, and more.

Web Browser: Mozilla, Google Chrome:

Web Browsers are software installed on your PC. To access the Web, you need a web browser, such as Google Chrome or Mozilla Firefox. There are four leading web browsers − Explorer, Firefox, Chrome, and Safari.

Operating System: Windows8/ Windows10:

The Windows operating system (Windows OS) for desktop PCs is more formally called Microsoft Windows and is actually a family of operating systems for personal computers. Windows dominates the personal computer world, running on majority of all personal computers – the remainder running Linux and Mac operating systems.

5.3.Development tools used

MATLAB has been used in the project due to its various advantages such as ease of use, platform independence, availability of predefined functions and device independent plotting. The Signal Processing Toolbox in MATLAB has been employed for performing signal processing, analysis and algorithm development.

MathWorks MATLAB R_2019a:

MATLAB (matrix laboratory) is a fourth-generation high-level programming language and interactive environment for numerical computation, visualization and programming.It allows matrix manipulations; plotting of functions and data; implementation of algorithms; creation of user interfaces; interfacing with programs written in other languages, including C, C++, Java, and FORTRAN; analyze data; develop algorithms; and create models and applications.It has numerous built-in commands and math functions that help you in mathematical calculations, generating plots, and performing numerical methods.

Communication System toolbox: MATLAB:

Communications Toolbox™ provides algorithms and apps for the analysis, design, end-to-end simulation, and verification of communications systems. Toolbox algorithms including channel coding, modulation, MIMO, and OFDM enable you to compose and simulate a physical layer model of your standard-based or custom-designed wireless communications system. The toolbox provides a waveform generator app, constellation and eye diagrams, bit-error-rate, and other analysis tools and scopes for validating your designs. These tools enable you to generate and analyze signals, visualize channel characteristics, and obtain performance metrics such as error vector magnitude (EVM). The toolbox includes SISO and MIMO statistical and spatial channel models. Channel profile options include Rayleigh, Rician, and WINNER II models. It also includes RF impairments, including RF nonlinearity and carrier offset and compensation algorithms, including carrier and symbol timing synchronizers. These algorithms enable you to realistically model link-level specifications and compensate for the effects of channel degradations. Using Communications Toolbox with RF instruments or hardware support packages, you can connect your transmitter and receiver models to radio devices and verify your designs with over-the-air testing.

Chapter 6

DESIGN PHILOSOPHY

The most basic function of a radar signal processor is detection of the presence of one or more targets of interest. Information about the presence of targets is contained in the echoes of the radar pulses. These echoes compete with receiver noise, undesired echoes from clutter signals, and possibly intentional or unintentional debris. The signal processor must somehow analyze the total received signal and determine whether it contains a desirable target echo. Target detection is the crucial first function performed by radars. Target detection is a prerequisite for all subsequent radar functions, such as tracking and target classification.

The methodology followed in this project falls under piecewise linear analysis i.e each algorithm was developed first and tested with all filters, all phases and all kinds of Doppler shifts was introduced and performance check has been be carried out independently. Then this has been developed and tested blocks have been inserted along with the required signal processing chain and the output has been displayed through image processing team. The results are compared with the system parameters like SNR, Range resolution, etc.

6.1 Data Flow

The data flow follows the path as shown in figure 3.1. The pulse compression technique is performed on the input data which is the raw data where the original signal is submerged in the noise and clutter. The Pulse Compression technique increases the SNR and range resolution. The Pulse Compression is followed by the Moving Target Indication (MTI) to remove the clutter, this is followed by Coherent Integration which further increases SNR and suppresses the noise and resolves the signal in the Doppler. To find the SNR and power of the received signal, power estimation is done. The Detection Process consists of

- Pulse Compression
- Moving Target Indication
- Coherent Integration
- Power Estimation

The Detection Algorithms are developed with the help of literatures and text books that are available. The purpose of detection algorithms in the project is to find the targets in the presence of noise, clutter and interference.

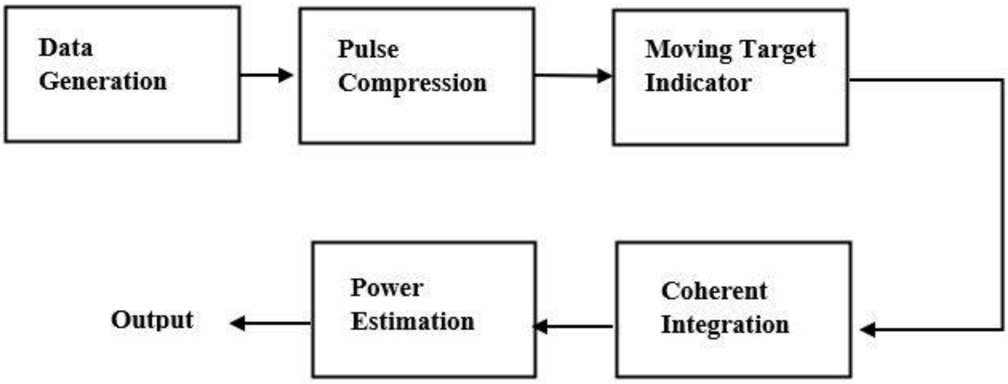

Fig 6.1: Data flow

6.2 Data Generation

The choice of waveform directly determines several fundamental radar system performance metrics such as SNR, the range resolution, the Doppler resolution, ambiguities in range and Doppler, range and Doppler side lobes and range Doppler coupling. These metrics are determined by such waveform attributes as the pulse duration, bandwidth, amplitude, and phase or frequency modulation. Linear FM has been the most used waveform in radar pulse compression. A chirp is a signal in which the frequency increases (up - chirp) or decreases (down - chirp) with time. It is less complex than other especially if the application permits the use of stretch. It usually requires weighting on the receive to reduce the -13.2 dB side lobes to the order of -30 dB, with a loss of about 1 dB. It is commonly used in sonar and radar, but has other applications, such as in spread spectrum communications. A linear frequency modulated waveform is defined by equation 4.1 and its instantaneous frequency is shown by

$$s(t) = e^{j\emptyset(t)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(6.1)$$

Where φ(t) is the instantaneous phase, given by the equation below

$$\emptyset(t) = 2\pi(f_0 t \pm Kt^2) \qquad -\frac{T}{2} \leq t \leq \frac{T}{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(6.2)$$

The instantaneous frequency as a linear function of time is expressed as

$$f_i = \frac{1}{2\pi}\left(\frac{d\emptyset}{dt}\right) \quad \text{……………………………………………………………………..(6.3)}$$

$$f_i = f_0 + kt \quad \text{…………………………………………………………………….(6.4)}$$

Where k is the slope and f_0 is the fundamental frequency

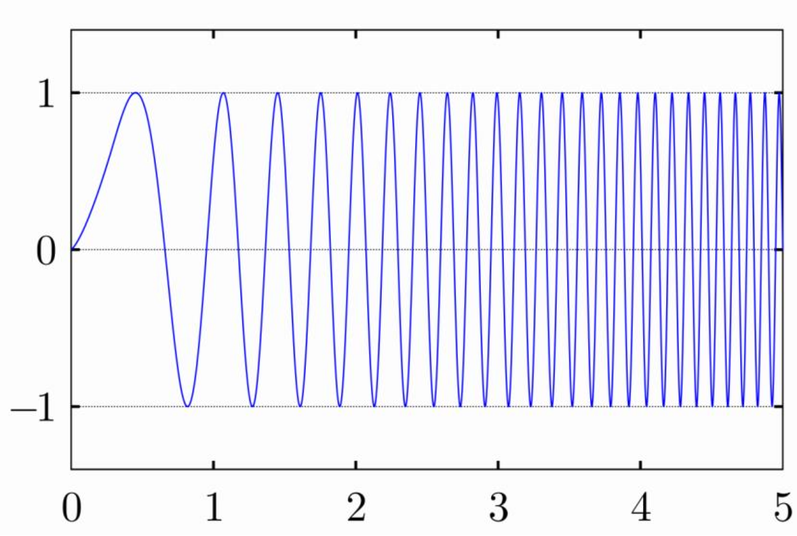

Fig.6.2 LFM up chirp waveform

6.3 Pulse Compression

6.3.1 Need for Pulse Compression

The received signal consists of transmitted signal which is completely submerged in noise. In such case, it is highly difficult to detect the target in the received signal. There is need for pulse compression in order to obtain high signal to noise ratio so that the signal gets highlighted within the noise. The pulse compression resolves the signal in the range and hence the targets are clear in the range.

6.3.2 General Description

Radars have the option of transmitting pulses of different lengths for different applications. Long pulses are more efficient in terms of average power usage, and typically high peak power signals should be avoided. They also have better detection capability than short pulses because there is more time for a target to be spotted. Narrow pulses would require high peak power, but they also have superior range resolution capabilities compared to long pulses. Ideally, low average power, high detection capability and high range resolution would all be achievable at the same time. A method called pulse compression makes this possible. In pulse compression, a long pulse can be used for transmission and then effectively turned into a narrow pulse. The long pulse is transmitted, and then the return is processed with a compression filter. According to Shkolnik, the compression filter "readjusts the relative phases of the frequency components so that a narrow or compressed pulse is again produced." Pulse compression involves the transmission of a long-coded pulse and the processing of the received echo to obtain a relatively narrow pulse. The increased detection capability of a long-pulse radar system is achieved while retaining the range resolution capability of a narrow-pulse system. Several advantages are obtained.

Transmission of long pulses permits a more efficient use of the average power capability of the radar. Generation of high peak power signals is avoided. The average power of the radar may be increased without increasing the pulse repetition frequency (PRF) and, hence, decreasing the radar's unambiguous range. An increased system resolving capability in Doppler is also obtained as a result of the use of the long pulse. In addition, the radar is less vulnerable to interfering signals that differ from the coded transmitted signal.

A short pulse has a wide spectral bandwidth. A long pulse can have the same spectral bandwidth as a short pulse if the long pulse is modulated in frequency or phase. The modulated long pulse with its increased bandwidth B is compared by the matched filter of the receiver to a width equal to 1/B. This process is called pulse compression. It can be described as the use of a long pulse of width to obtain the resolution of a short pulse by modulating the long pulse to achieve a bandwidth $B >> 1/T$, and processing the modulated long pulse in a matched filter to obtain a pulse width $\tau = 1/B$. Pulse compression allows radar to simultaneously achieve the energy of a long pulse and the resolution of a short pulse without the high peak power required of a high energy short-duration pulse.

A long pulse may be generated from a narrow pulse. A narrow pulse contains a large number of frequency components with a precise phase relationship between them. If the relative phases are changed by a phase-distorting filter, the frequency components combine to produce a stretched or expanded pulse. This expanded pulse is the pulse that is transmitted. The received echo is processed in the receiver by a compression filter. The compression filter readjusts the relative phases of the frequency components so that a narrow or compressed pulse is again produced. The pulse compression ratio is the ratio of the width of the expanded pulse to that of the compressed pulse. The pulse compression ratio is also equal to the product of the time duration and the spectral

bandwidth of the transmitted signal. Practically, the pulse compression is simply an implementation of the matched filtering process described later. The compression filter is the matched filter. The output of the matched filter is the compressed pulse and the range of observed targets is found.
For a radar performing pulse compression, it is important to have a large time-bandwidth
15 products. Generally, the larger time-bandwidth product a radar system has, the better. It helps ensure a stable output power level, which is important to pulse compression

6.3.3 Matched Filter

Pulse Compression radar is a practical implementation of a matched filter system. A filter is matched to a signal if the signal is the complex conjugate of the time inverse of the filter's response to a unit impulse. This is achieved by applying the time inverse of the received signal to the compression filter. The output of this matched filter is given by the convolution of the signal h(τ) with the conjugate impulse response h*(-τ) of the matched filter.

$$Y(t) = \int_{-\infty}^{\infty} h(\tau)\, h^*(t - \tau) d\tau \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6.5)$$

In frequency domain the matched filter involves the multiplication of two frequency domain vectors with an application of complex conjugate to one of the vectors. The impulse response of matched filter is given by

$$H(\omega) = KS^*(\omega)e^{-j\omega t}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6.6)$$

Where
K is the constant
t is the delay
S*(ω) is the complex conjugate of input s(t)

The matched filter output for pulse compression in frequency domain is given by

$$G(\omega) = H(\omega)S(\omega)\ldots\ldots\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6.7)$$

The matched filter results in a correlation of the received signal with the transmitted signal. Hence, correlation processing is equivalent to matched filtering. The convolution in time domain is equal to the multiplication in frequency domain. The output of the matched filter is the compressed pulse, which is given by the inverse Fourier transform of the product of the signal spectrum and the matched filter response. In the presence of Doppler frequency shift, a bank of matched filters is required, with each filter matched to a different frequency so as to cover the band of expected Doppler frequencies.

6.3.4 Design and Development

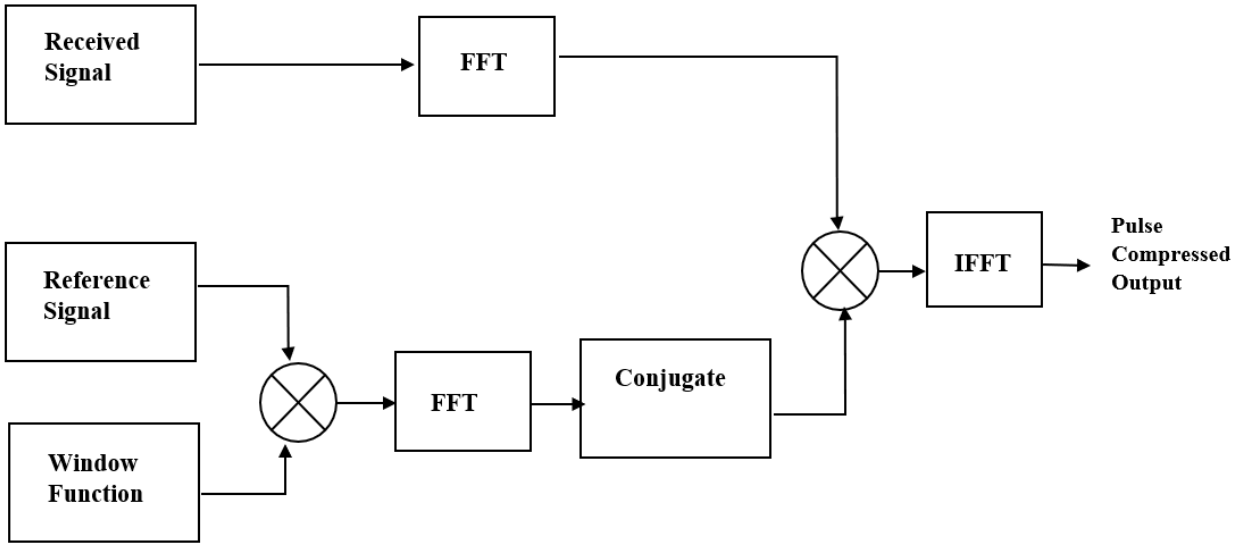

Figure 6.3 Block Diagram of Pulse Compression

The FFT is performed on the reference signal which is obtained from the data as shown in. 1024-point FFT is performed on the reference and the input signal. The conjugate of the reference signal in frequency domain is multiplied with the input signal in frequency domain which results in the correlation of reference signals and the input signal in frequency domain. The frequency domain is chosen for the convenience for performing the correlation. The output of this is then converted back to the time domain by taking the inverse FFT on the output. The received signal consists of the original signal which is submerged in the noise. In Pulse Compression, due to matched filtering on the input and the reference signal, the signal gets resolved in the range.

6.4 Moving Target Indicator (MTI)

In this section, the need for moving target indicator and the general description of it are discussed. This is followed by the design and development of the Moving target indicator algorithm and the expected results of it.

6.4.1 Need for Moving Target Indicator

Clutter Spectrum is normally concentrated around DC (Freq = 0) and multiple integers of the radar PRF. The purpose of Moving Target Indicator (MTI) is to suppress target-like returns produced by clutter and allow returns from moving targets to pass through with or no degradation.

6.4.2 General Description

MTI processing applies a linear filter to the slow time data sequence to suppress the clutter component. Figure illustrates the process. the type of filtering needed can be understood by considering the notional spectrum of the slow time data. The output of high pass MTI filter will be a modified slow – time signal containing components due to noise and possibly, one or more targets, this signal is passed to a detector typically based on amplitude or squared amplitude of data and possibly involving noncoherent detection as well. If the amplitude of the filter signal exceeds the threshold, target will be declared; otherwise the data is declared to represent the interface only. The Doppler shift in frequency caused by a moving target permits the pulse radar to discern moving targets in the presence of fixed targets. The target echo of a moving target competes with target echoes of fixed targets (which do not have Doppler shifts) in the same radar resolution cell. The fixed targets enter this radar resolution cell if they are at the same range as the moving target but not necessarily at the same angular position. The fixed target echoes may be received from the side lobes as well as from the main lobe of the antenna. The fixed or slow-moving targets to be eliminated by moving target indicator can be ground clutter, sea clutter, rain, snow or chaff. Moving target indicator is only used for fixed target rejection. Moving target indicator systems are usually operated at relatively low pulse repetition rates to provide unambiguous range with ambiguous Doppler. MTI radars employ delay line cancellers to eliminate the fixed targets by a sweep - to - sweep subtraction,

6.4.3 Pulse Cancellers

The major MTI design decision is the choice of the particular MTI filter to be used. MTI filters are typically low-order, simple *finite impulse response* (FIR; also called tapped delay line or nonrecursive) designs. Indeed, some of the most common MTI filters are based on very simple heuristic design approaches. For example, suppose a stationary radar illuminates a stationary clutter scatterer. After demodulation, the measured sample of the received signal in the appropriate

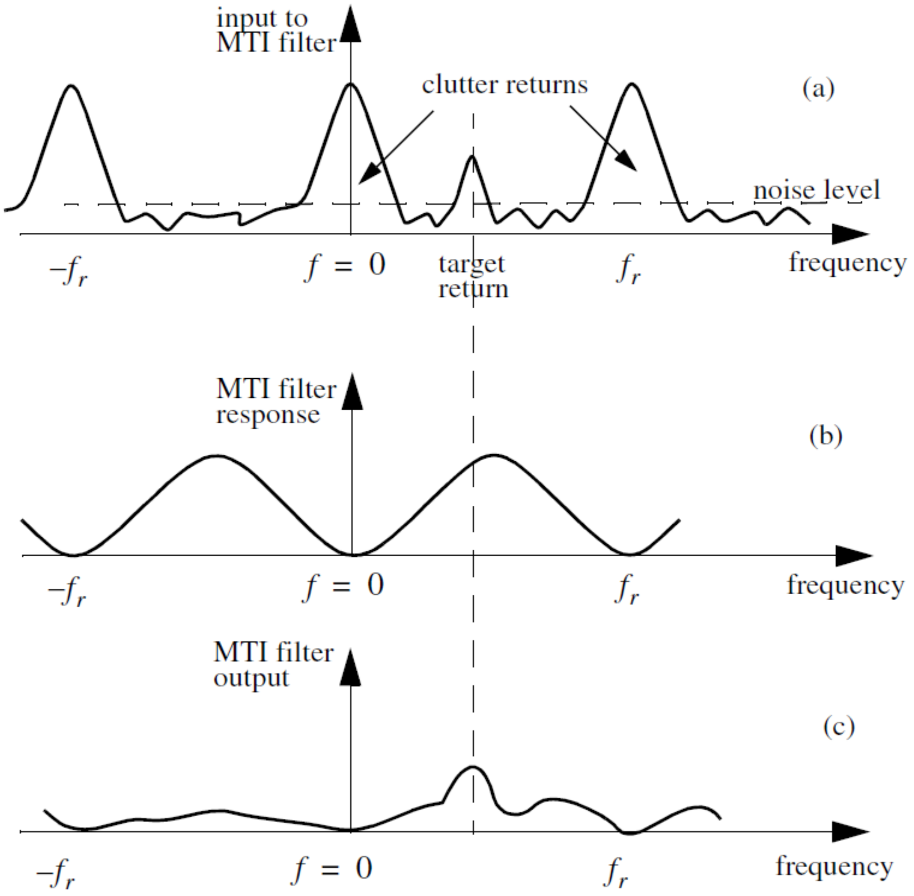

Figure 6.4 (a) Typical Radar Return PSD When Clutter and Target is Present (b) MTI Filter Frequency Response. (c) Output from an MTI Filter

range bin will be of the form $Ae^{j\varphi}$ for some amplitude A and phase φ. If the measurement is repeated, the same value will be measured again (ignoring noise). Subtracting the echoes from successive pairs of pulses would cancel the clutter return completely. Now consider the same scenario, but with a moving target. While the amplitude of the successive echoes may be identical, the range to the target will change between pulses by an amount $\delta R = vT$ m, where v is the radial velocity of the target and T is the pulse repetition interval. Consequently, the phase of the echo will change by $(4\pi/\lambda)\delta R$ radians as can be seen in equation (17.2). Subtracting these two measurements will not result in a zero-signal due to the different phases. This reasoning motivates the two-pulse MTI canceller, also referred to as the single canceller or first-order canceller. Figure 17-6a illustrates the flowgraph of a two-pulse canceller, which is an especially simple FIR digital filter

The input data are a sequence of baseband complex (in-phase and quadrature, or I and Q) data samples from the same range bin over successive pulses, forming a discrete-time sequence $y[m]$ with a sampling interval T equal to the pulse repetition interval.

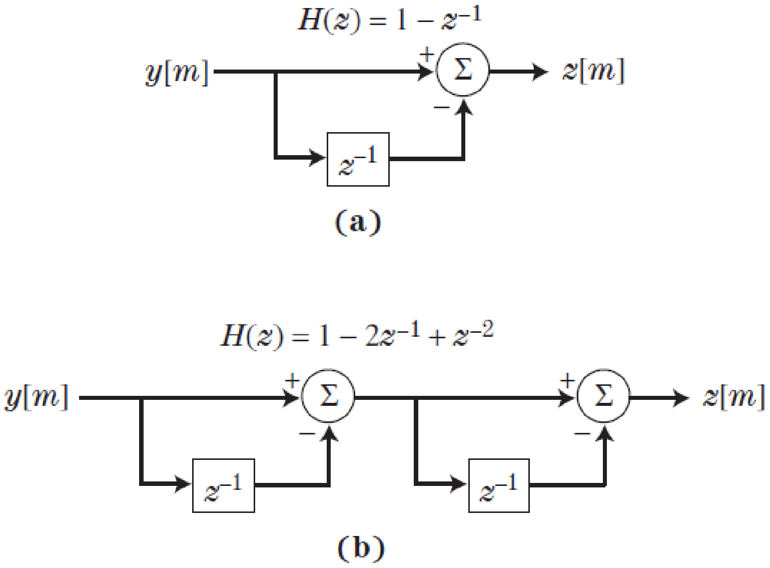

Fig: 6.5 Transfer functions of MTI cancellers. (a) Two-pulse canceller. (b) Three-pulse canceller

The discrete-time transfer function of this filter is simply $H(z) = 1 - z^{-1}$. The frequency response as a function of analog Doppler frequency fd in hertz is obtained by setting $z = e^{j2\pi fd\,T}$:

$$H(f_d) = (1 - z^{-1})|_{z=e^{j2\pi f_d T}} = 1 - e^{-j2\pi f_d T} \ldots\ldots\ldots\ldots\ldots\ldots (6.8)$$

$$= e^{-j\pi f_d T}\left(e^{+j\pi f_d T} - e^{-j\pi f_d T}\right)$$

$$= 2je^{-j\pi f_d T}\sin(\pi f_d T)\ldots\ldots\ldots\ \ldots\ldots (6.9)$$

The frequency response may also be expressed in terms of normalized frequency $f = fdT$ cycles/sample or the radian equivalent, $\hat{\omega} = \omega T = 2\pi fdT$ radians/sample. For example, in terms of normalized radian frequency, the frequency response of the two-pulse canceller is

$$H(\hat{w}) = 2je^{-j\hat{w}/2}\sin\hat{w}/2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6.10)$$

Note that as fd ranges from $-PRF/2$ to $+PRF/2$ $(-1/2T$ to $+1/2T)$, $\hat{f}$ ranges from −0.5 to

+0.5 and $\hat{\omega}$ from $-\pi$ to $+\pi$.

The two-pulse canceller imposes a very low computational load; Figure 17-6a shows that its implementation requires no multiplications and only one subtraction per output sample. As Figure 17-7a shows, however, it is a poor approximation to an ideal high-pass filter for clutter suppression. The next traditional step up in MTI filtering is the three-pulse (second-order or double) canceller, obtained by cascading two two-pulse cancellers. The flowgraph and frequency response are shown in Figures 17-6b and 17-7b. The three-pulse canceller improves the null depth and width in the vicinity of zero Doppler and requires only two subtractions per output sample, but there is still a large variation in the filter gain or attenuation for moving targets at various Doppler shifts away from zero Doppler. Despite their simplicity, the two-and three-pulse cancellers can be very effective against clutter with moderate to high pulse-to-pulse correlations. This is because highly correlated clutter corresponds to a narrow power spectrum, so that a high fraction of the clutter energy falls within the filter notch at zero Doppler shift. Despite its simplicity, the two-pulse canceller is therefore nearly a first-order matched filter for MTI processing when the clutter-to-noise ratio is high and the successive clutter pulses are highly correlated. In the limit of very high clutter-to-noise ratio and perfectly correlated clutter, the two-pulse canceller is exactly the first-order matched MTI filter.

6.4.4 Design and Development

6.4.4.1 2 Pulse Canceller (A single delay canceller)

A single canceller filter is shown in following Figure 3.5. The “Single” stands for a single delay line. The single delay canceler is often called a “two-pulse canceler” since it requires two distinct input pulses before an output can be read. The delay T must be equal to the inverse of the Pulse Repetition Frequency (PRF). Intuitively, it is clear that the filter output at any given instant “t” is constructed from the input signal at “t” minus the signal at t-T. In other words, the present pulse return from a given range is compared with previous pulse return from the same range. Only the difference between two appears at the output. A coherent detector can yield difference as big as twice the signal amplitude due to Doppler induced phase difference from pulse to pulse. The MTI can be implemented in radar by subtracting the range gates at consecutive Pulse Repetition Intervals

(PRIs). Hence if there are N PRIs, the output of MTI will be N-1 PRIs. MTI is used to eliminate the fixed or slow-moving targets

6.4.4.2 3 Pulse cancellers (Double delay line canceller)

Double cancelers are often called "three-pulse cancelers" since they require three distinct input pulses before an output can be read. The double line canceler impulse response is given by

$$h(t) = \delta(t) - 2\delta(t-T) + \delta(t-2T)$$

Again, the names "double delay line" canceler and "double canceler" will be used interchangeably. The power gain for the double delay line canceler is

$$|H(\omega)|^2 = |H_1(\omega)|^2 \, |H_1(\omega)|^2$$

Where |h(w))\^2 is the single line canceler power gain .

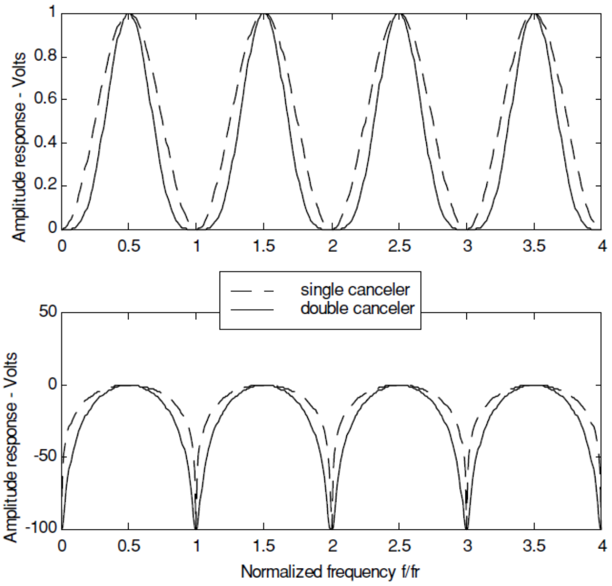

Fig 6.6: A comparison between the output of single and double canceller

6.5 Coherent Integration

In this section, the need for coherent integration and the general description of it are discussed. This is followed by the design and development of the coherent integration algorithm and the expected results of it.

6.5.1 Need for Coherent Integration

In pulse compression, the received signal is resolved only in range therefore the coherent integration algorithm is needed to resolve the signal in Doppler also. The coherent integration also suppresses the noise and interference, thus increasing the signal to noise ratio.

When a target is illuminated by the radar beam it normally reflects numerous pulses. The radar probability of detection is normally enhanced by summing all (or most) of the returned pulses. The process of adding radar echoes from many pulses is called radar pulse integration. Pulse integration can be performed on the quadrate components prior to the envelope detector. This is called coherent integration. Coherent integration preserves the phase relationship between received pulses, thus builds up in the signal amplitude is achieved. Alternatively, pulse integration performed after the envelope detector (where phase relation is destroyed) is called non-coherent integration.

6.5.2 General Description

Coherent integration is a type of multi-pulse detection. In this technique, the signal components are added in phase, i.e., coherently. This is often described as adding on a voltage basis, since the amplitude of the integrated signal component increased by a factor of N, with a result that signal energy increased by N^2. The noise samples, whose phases varied randomly, are added on a power basis. It is the alignment of the signal component phases that allowed the signal power to grow faster than the noise power.

Coherent Integration is the process of summing the contents of several samples of the same range bin in both amplitude and phase. It increases the signal to interference ratio well if the interference is random. In the process of coherent integration, windowing is employed to increase the gain and to suppress the side lobe levels of the input signal. This increases the strength of the main signal in the input signal.

Coherent Integration is a type of multi-pulse detection. This technique adds pulses as voltages with knowledge of phase before applying the threshold test. Equivalently, Coherent Integration can be considered to be vector addition of the multiple returns. It suppresses noise, clutter and some forms of ECM. Noise is suppressed by its randomness, and clutter by the fact that it occupies a different Doppler bin than the target echo. Non-coherent integration suppresses only noise.

6.5.3 Design and development

The integration is done for all received PRIs. The N-point-FFT to select depends on the number of PRIs. Accordingly, the N-point FFT is selected, if number of PRIs are not multiples of 2, it is required to do pre-zero and post-zero padding to fill up the input FFT points. In coherent integration the matrix performs column wise FFT**.** The input to the coherent integration is the output of the moving target indication, though the target is clear in the range it is masked in the Doppler. The noise and interference are suppressed with the help of coherent integration and also the target is resolved in Doppler.

6.6 Power Estimation

After the coherent integration the Programmable Signal Processor (PSP) performs the estimation of power by computing the magnitude of the I and Q components for all range gates of all Pulse Repetition Interval (PRI). The magnitude is given by

Power = (I2 + Q2)

Chapter 7

RESULTS

The simulation has been done in MATLAB. After the generation of data and detection algorithms, the code is run on MATLAB and the outputs are checked for their resemblance to the actual scenario. The test results have been satisfactory for numerous trials and simulation. The results have been plotted and analyzed in this chapter. The implementation begins with generation of data followed by the detection algorithms.

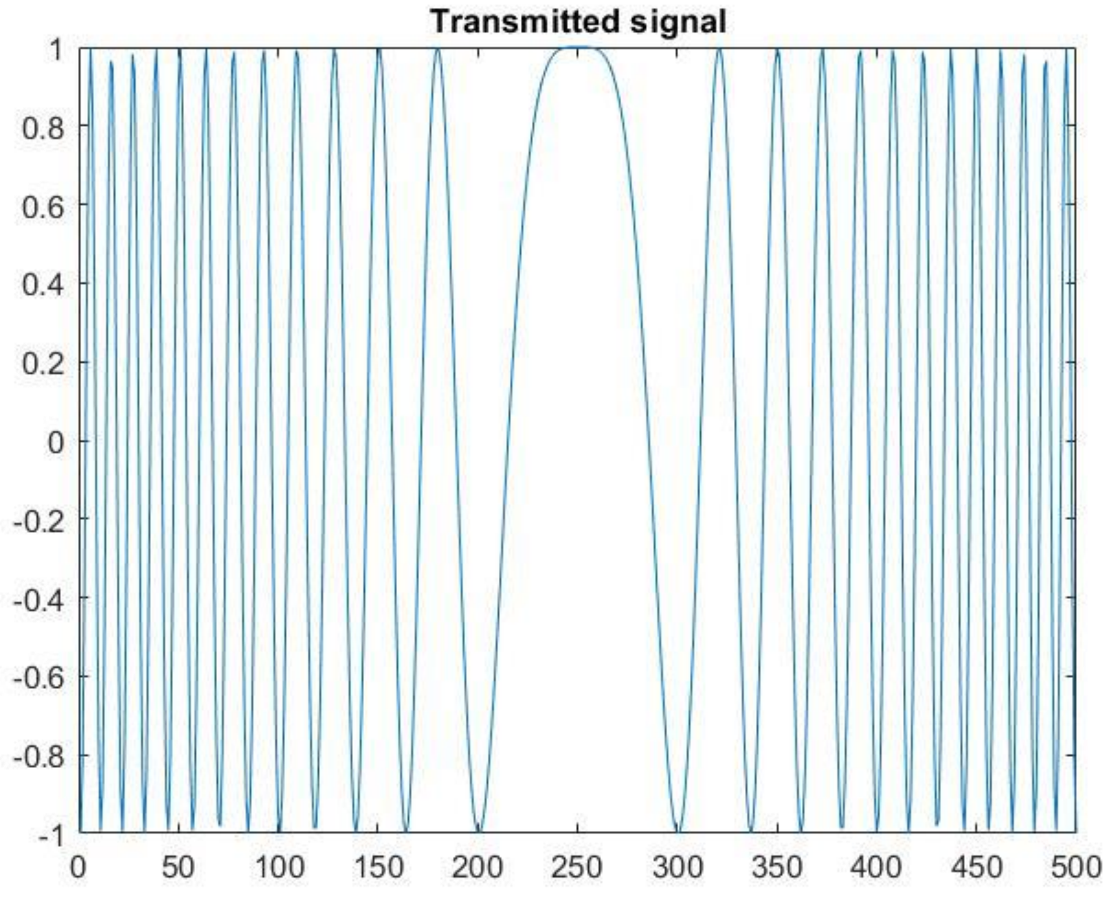

Fig 7.1 LFM Transmitted signal

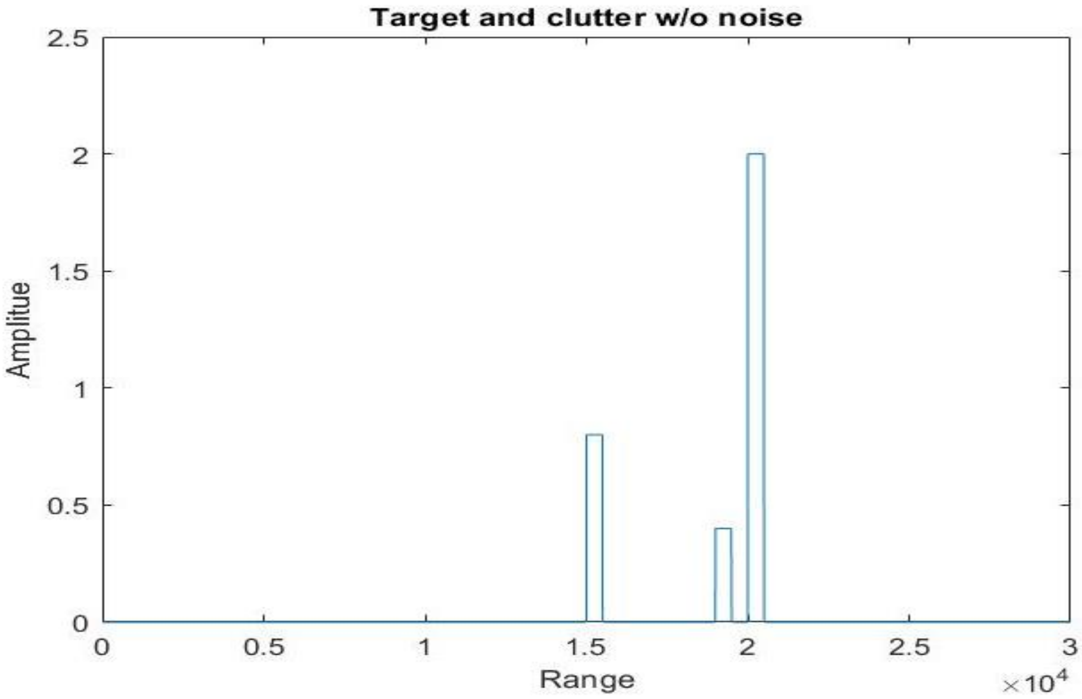

Fig 7.2 In-phase clutter along with target

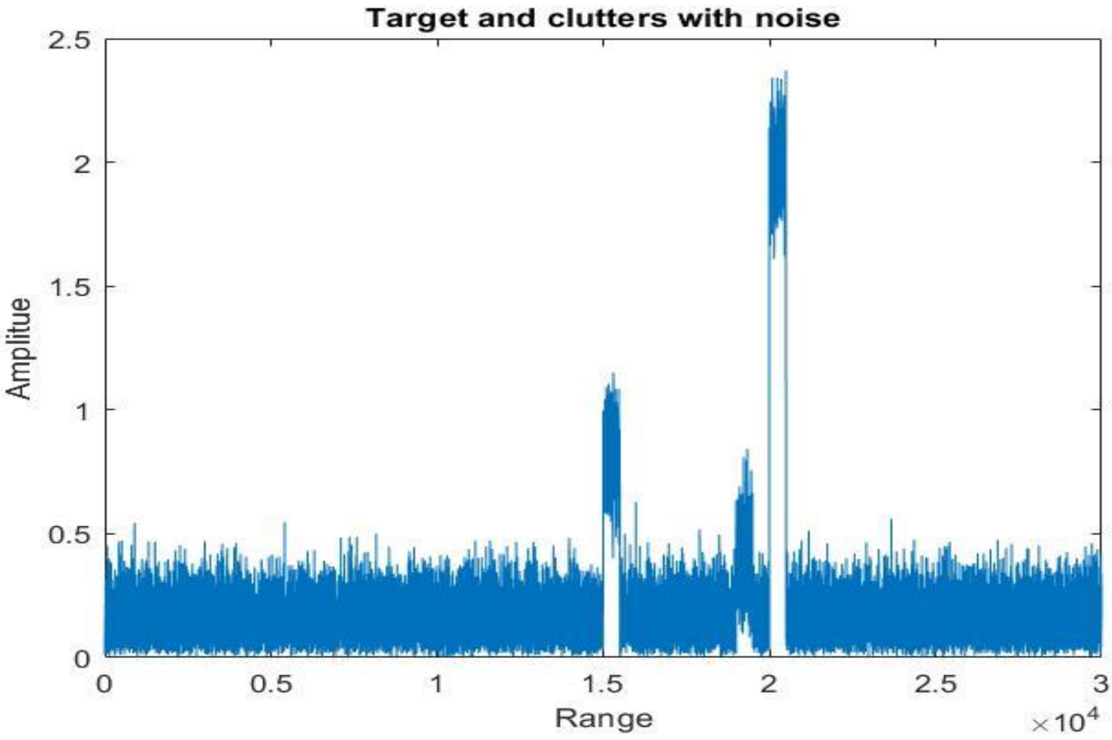

Fig. 7.3 In-phase clutter along with target and noise

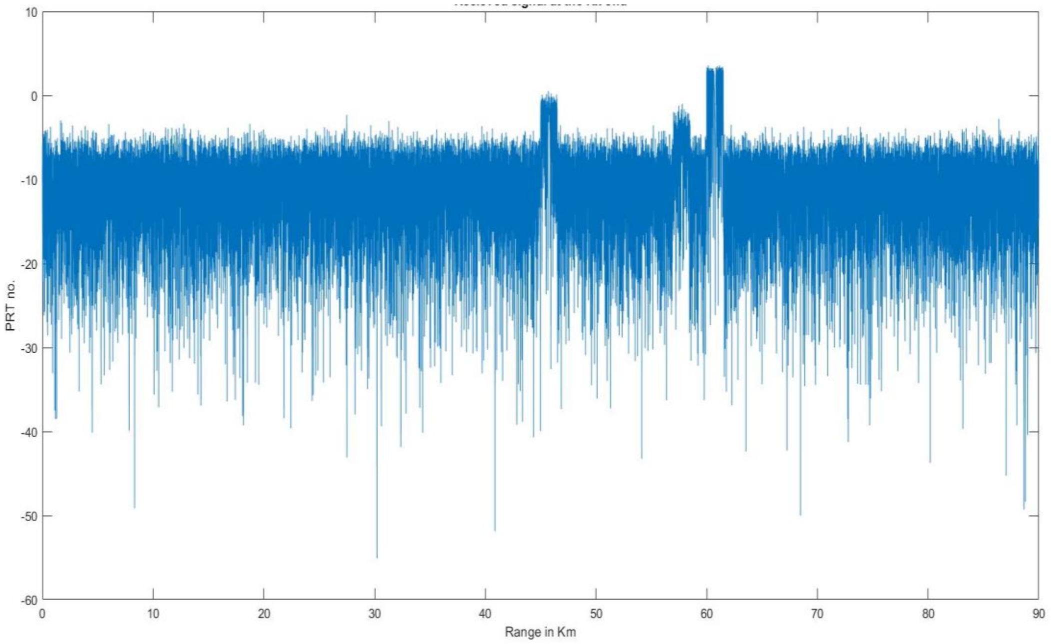

Fig 7.4 Received signal with target, clutter and noise

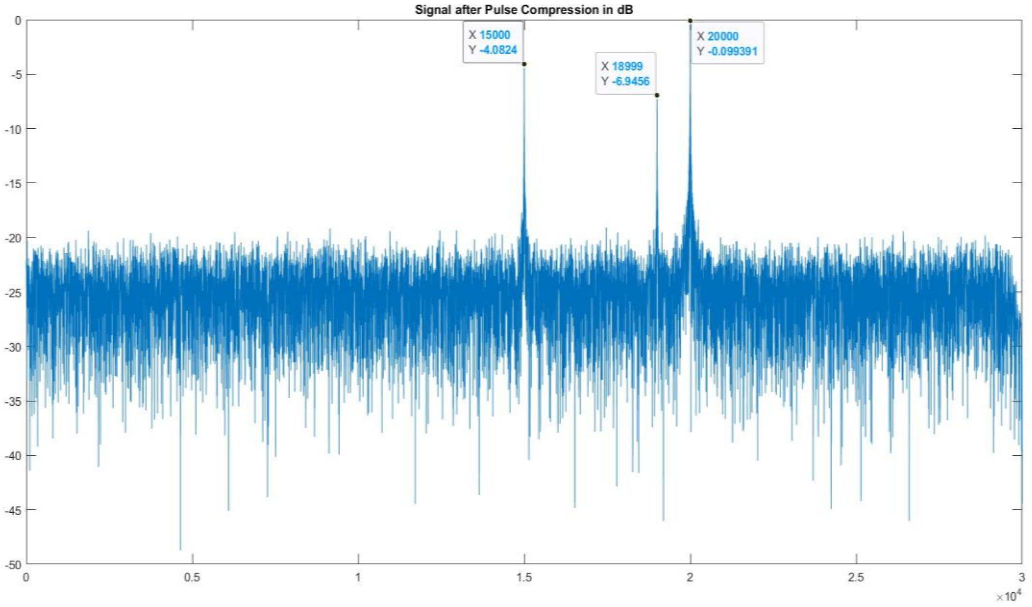

Fig 7.5: Signal after Pulse Compression

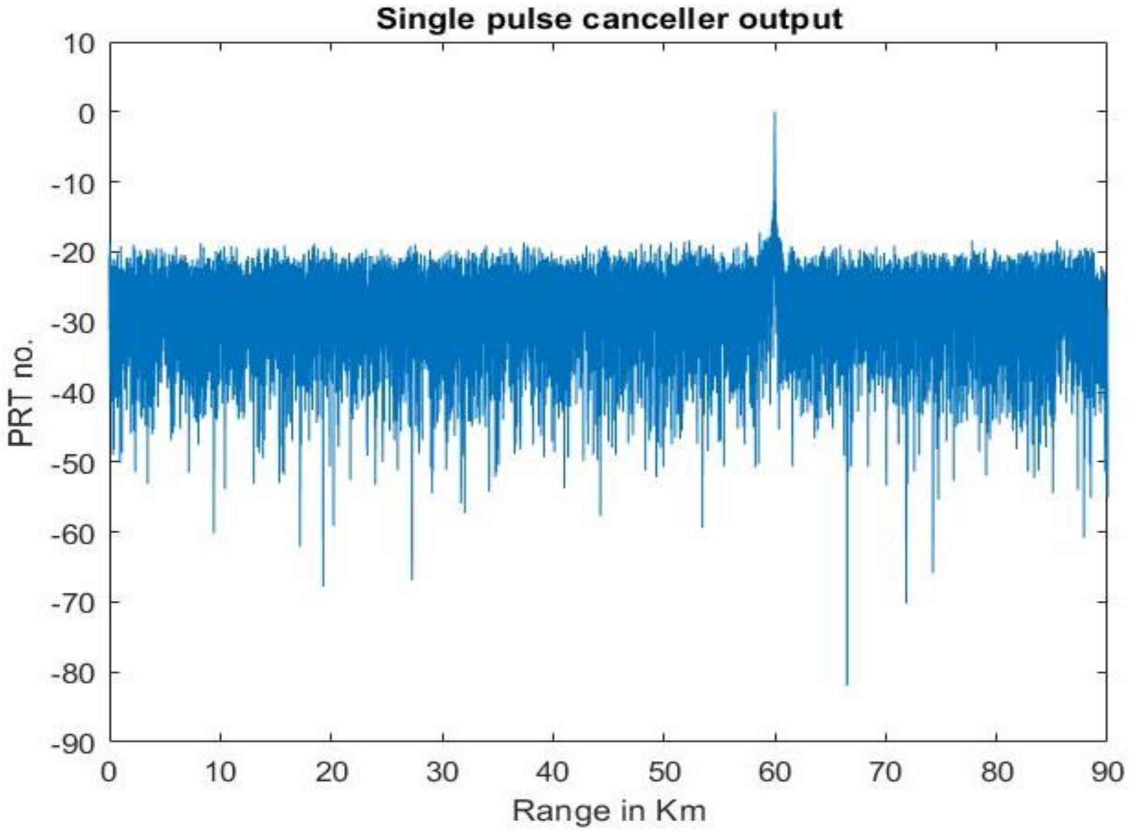

Fig 7.6 Single pulse canceller output (MTI Stage one output)

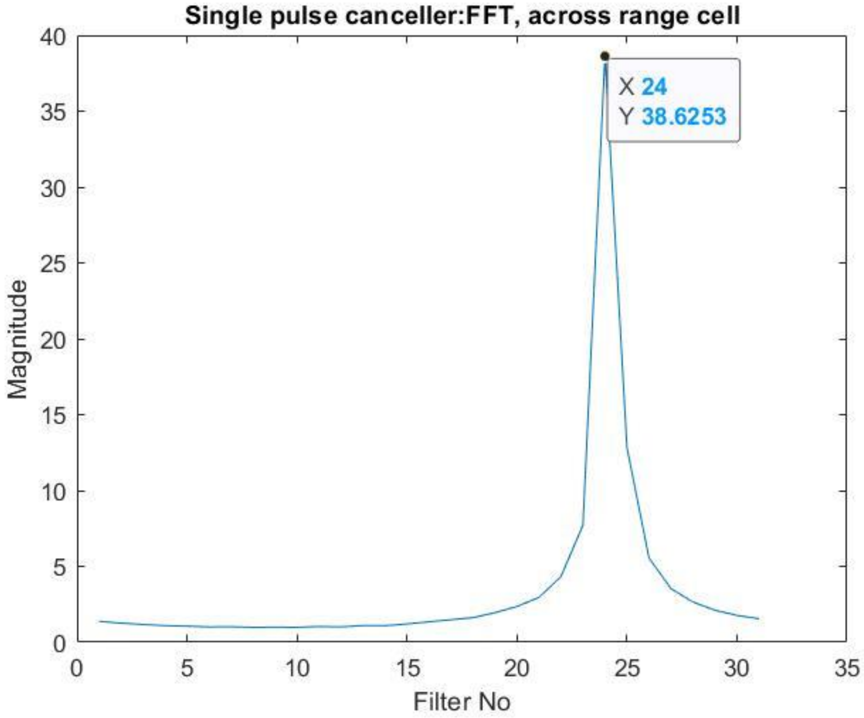

Fig 7.7 FFT output of single pulse canceller

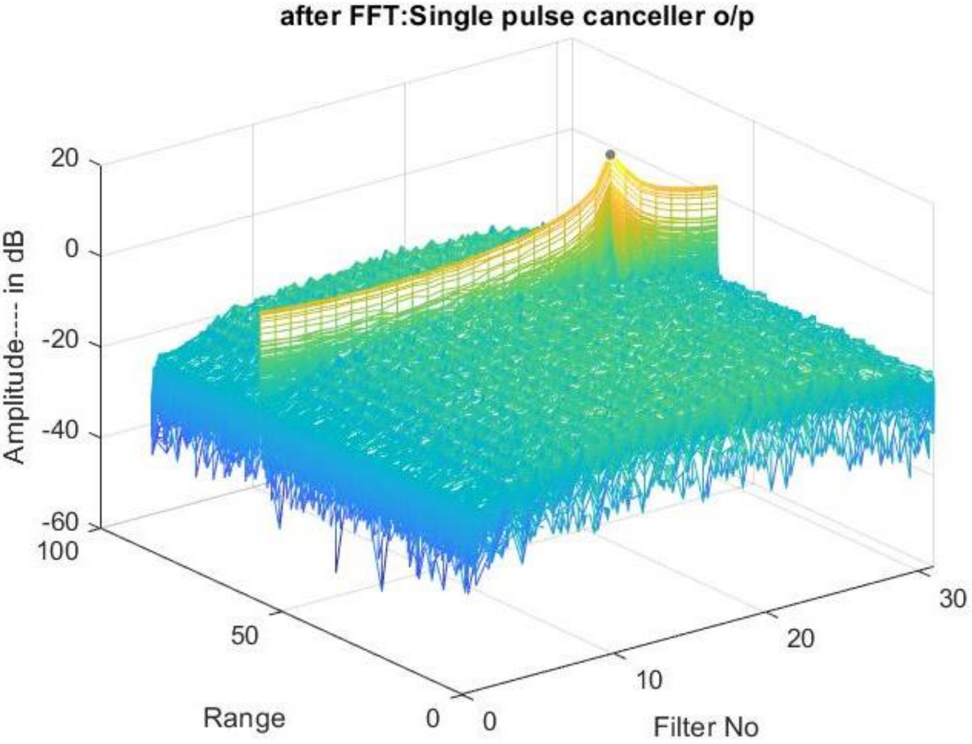

Fig 7.8 Mesh FFT output of single pulse canceller

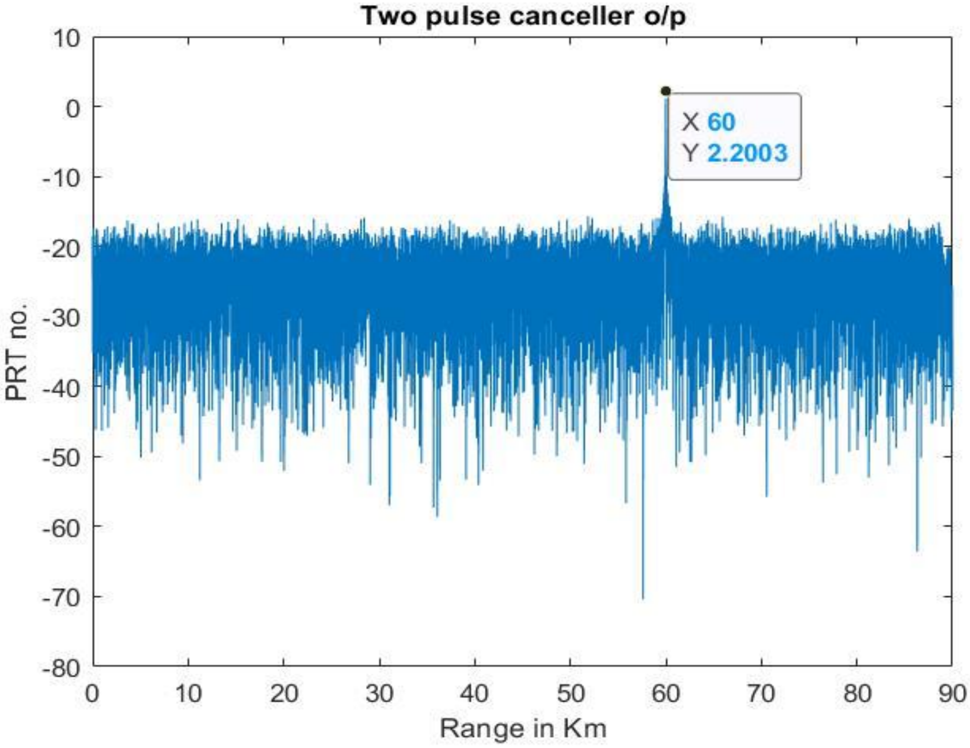

Fig 7.9 Two pulse canceller output (MTI Stage two output)

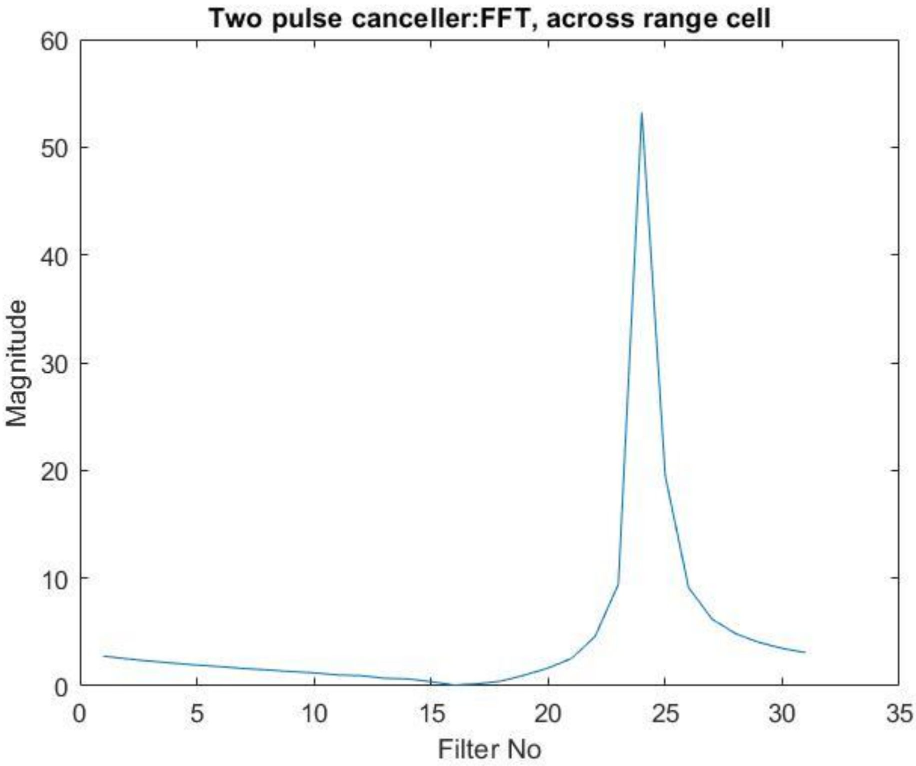

Fig 7.10 FFT output of two pulse canceller

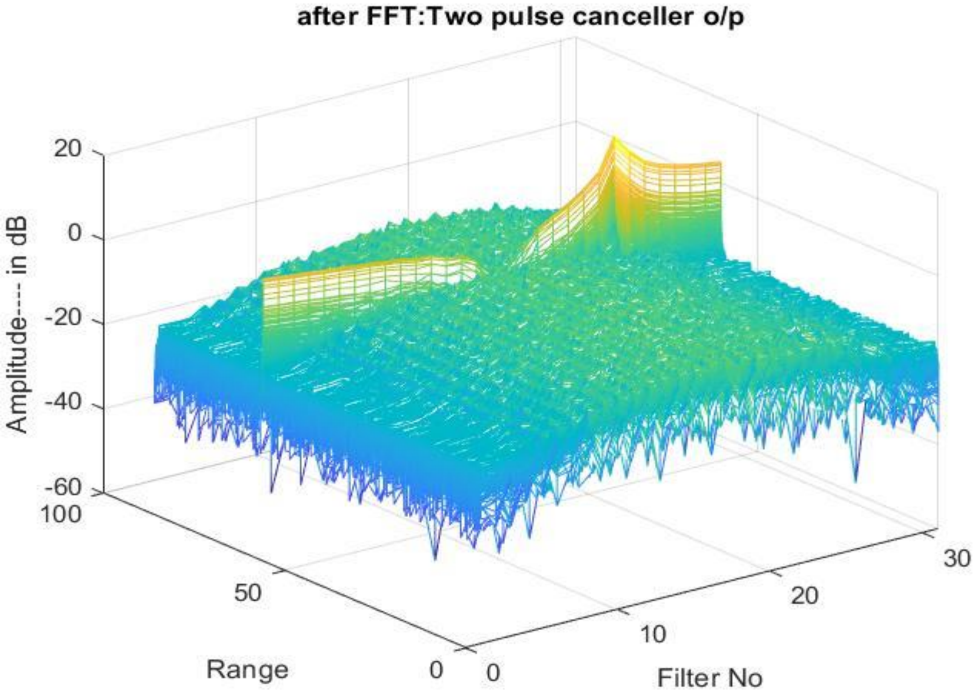

Fig 7.11 Mesh FFT output of two pulse canceller

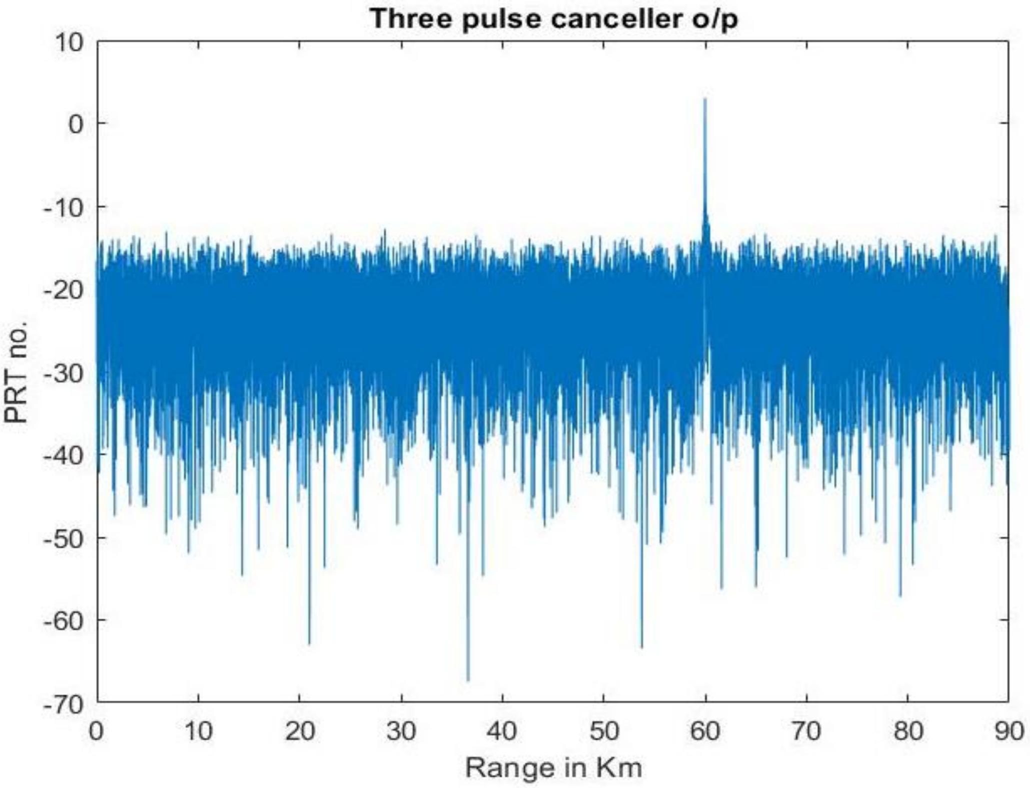

Fig 7.12 Three pulse canceller output (MTI Stage three output)

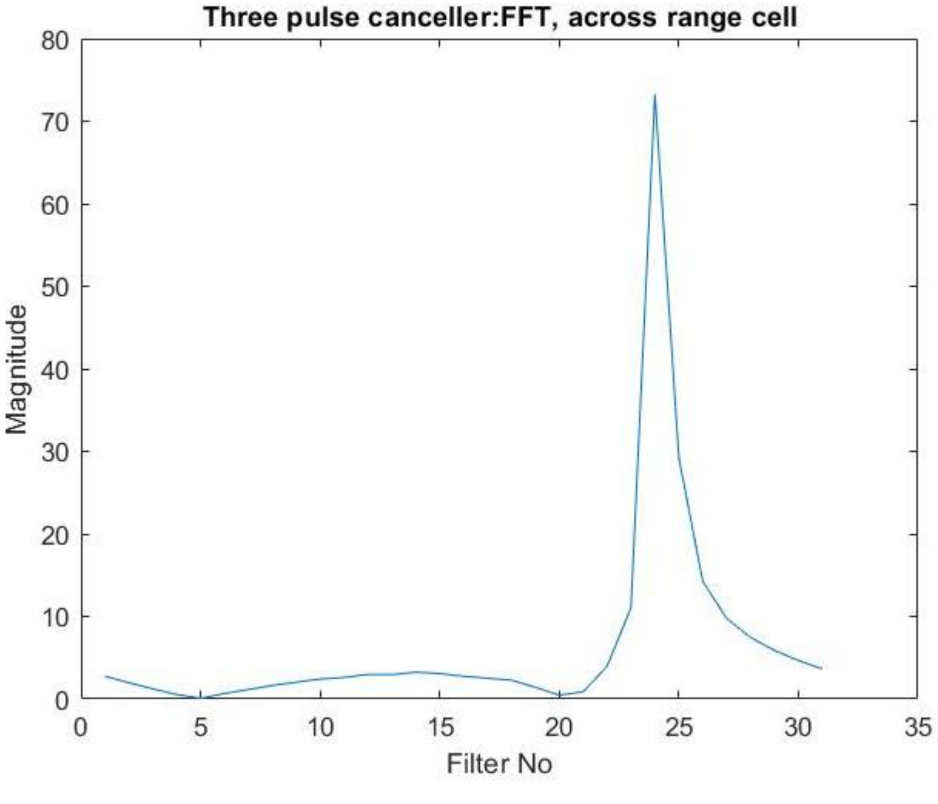

Fig 7.13 FFT output of three pulse canceller

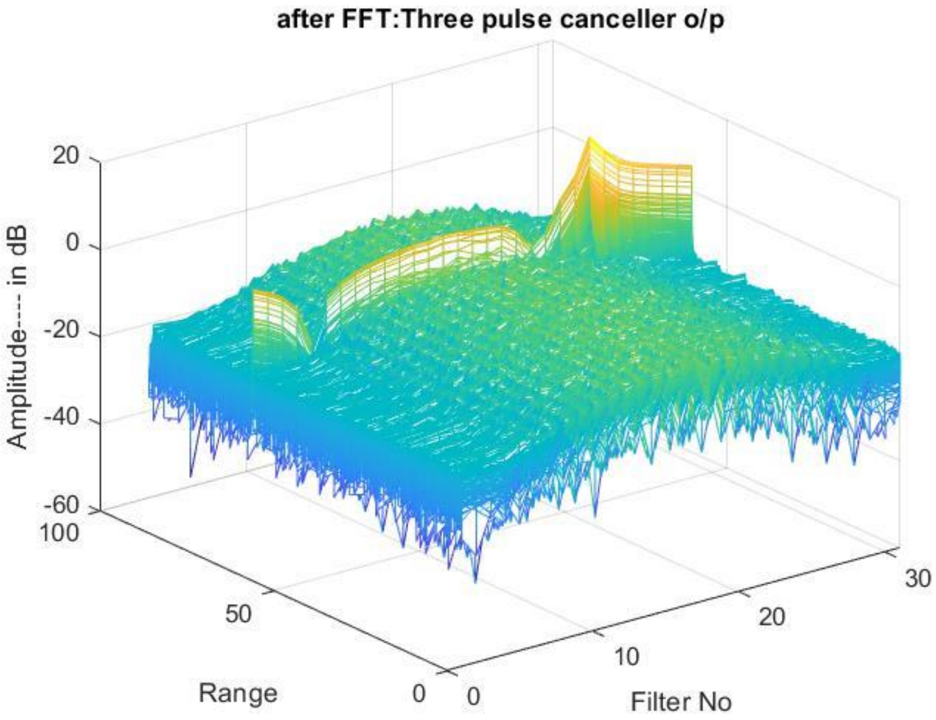

Fig 7.14 Mesh FFT output of two pulse canceller

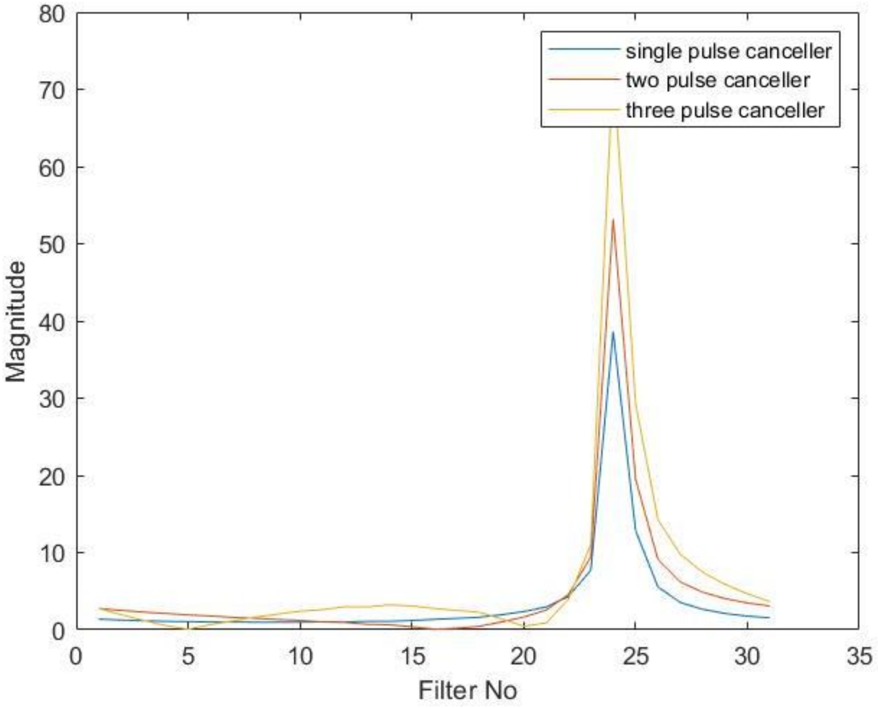

Fig 7.15 Comparison of FFT outputs of the 3 MTI configurations

The received signal consists of noise and clutter which is due to external or internal factors or both. Hence the noise is generated randomly and added with the transmitted signal for each pulse to obtain the received signal and this is repeated for all the pulses. The signal thus obtained is submerged in noise as shown in figure 7.1.

In figure 7.4, it is highly difficult to detect the target in the received signal. There is need for pulse compression in order to obtain high signal to noise ratio so that the signal gets highlighted within the noise. The pulse compression resolves the signal in the range by performing the correlation of reference signal and the received signal in the frequency domain. The output of this is then converted back to the time domain by taking the inverse FFT on the output. The result obtained in time domain as shown in figure 7.5 is the pulse compression output which is the compressed signal.

Moving target indicator is only used for fixed target rejection. Moving target indicator systems are usually operated at relatively low pulse repetition rates to provide unambiguous range with ambiguous Doppler. MTI radars employ delay line cancellers to eliminate the fixed targets by a sweep - to - sweep subtraction. The MTI is used to remove stationary clutter. Figure 7.6, 7.9 and 7.11 shows the output of single, double and three pulse cancellers respectively

After the MTI, the target is still not clear as it contains noise. Hence the coherent integration algorithm is needed to resolve the signal in Doppler also. The coherent integration suppresses the noise and interference, thus increasing the signal to noise ratio.

Fig 7.8 shows the CI output of a single pulse canceller. It can be seen that the SNR is not great and noise cancellation is poor. In Fig 7.11, it is seen that there is better SNR ratio and noise dip is there as the target approaches. Fig 7.14 shows the CI output of a three-pulse canceller. It can be seen that it provides the best SNR among all the three configurations.

Fid 7.15 shows a comparison between the FFTs of all the three configurations of MTI. From this, it can be inferred that the Third-order MTI provides the best SNR.

Chapter 8

CONCLUSION AND FUTURE SCOPE

8.1. Conclusion

In this project, an efficient radar detection method is presented. The signal processing chain, along with given block combinations successfully eliminates the clutters present in the received data and enhances the target visibility.

The comparison has been done for three different configurations of MTI along with coherent integration done for each MTI configuration output.

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8.2. Future Scope

The detection process can still be improved when noise and clutter is present. Further enhancement of target isolation can be achieved by using SVD and EVD of Hankel Matrix. Also, this technique of signal processing can be extended to image processing models of GPR and results or target identification can be made more effective.

By using wavelet transformation many of the signal and image processing algorithms used at present can be eliminated. And also, some of the algorithms can be improved for better resolution in Range and Doppler.

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