Design & Simulation of GPS Based Radar Altimeter

Using

GPS Signal Acquisition

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Radar

Global positioning system (GPS)

Synthetic aperture radar.

The Arabic word, *Bismillah*, 'In the name of God',
created in the shape of an ostrich by Sudanese artist Hassan Musa. Courtesy of Grandir Editions.

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I certify that except where due acknowledgements has been made, the work has not been submitted previously, in whole, to qualify for any other academic award, the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program, and any editorial work paid or unpaid, carried out by third party is acknowledged.

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Abstract

GPS signals are widely used for navigation and positioning purposes. However, this thesis presents a method for utilizing reflected Global Positioning System (GPS) signals to measure distance on board an Arial platform. Under current circumstances, airborne systems are using different methods for the calculation of their altitude e.g. barometer and Radar Altimeter etc. Efforts have been made in this project to design, simulate and present experimental results of a passive altitude calculation system by comparison of directly received GPS signals and surface reflected signals.

A software code in Matlab has been developed for the comparison of direct and reflected GPS signals. Dedicated hardware was designed for simultaneous acquisition of direct and reflected signals, having two separate antennas. The hardware was initially designed for GPS based bi-static SAR (synthetic aperture radar) purpose. However the acquired GPS signals can also be utilized for altimetry measurements, ranging and calculation of ocean wave heights etc. The experiments and the results concluded that the reflected GPS signals can be used for calculation of distance by correlation with direct signals. The purpose of this thesis is to identify potential applications of reflected GPS signals, it also provides the basis to prepare a cost effective GPS reflected signal based Radar Altimeter.

Dedication

I initially created this page to honor those who influenced my life in a profound way. But now this page is something much, much more personal. Dedicating a book is one of the most exquisite acts of love ones can perform. "I would argue that it is even more beautiful to dedicate this one to you without saying your names".

- My Teachers Thank you very much for being with me, supervised me, help me to remain on track to achieve my carrier targets. I will obey you for the rest of my life as a commander, father, friend and the most un-conditional guidance personality of the world.

- My Parents: Thank you for your unconditional support with my studies. I am honoured to have you as my parents. Thank you for giving me a chance to prove and improve myself through all my walks of life. I tried to spend my life fulfilling your dreams which were left unveiled. Please do not ever change. I love you so much.

- My Sisters: Thank you for believing in me, hoping that with this research I have proven to you that there is no mountain higher as long as God is on our side. Hoping you will realise it once again and will be able to fulfil your and parents dreams.

- My Friends: Without you guys, your confidence, your fights and lots of encouragement, this mountain of success could possibly remain a morning dream. Thank you for being there for me.

(Ehtesham Mujtaba Awan)

Acknowledgments

- I thank almighty God for giving me the courage and determination, as well as guidance in conducting this research study, despite all difficulties.
- I wish to extend my utmost gratitude to all fellows for their wonderful participation and cooperation.
- I explicitly like to express my gratitude to my supervisor Dr. Usman for his excellence in his field and to identify road of success. You were so wonderful to me. You made me believe that I had so much strength and courage to persevere even when I felt lost. You showed me light in a tunnel where everything was dark. You were very tolerant and determined to see me through. You were such wonderful motivator even when copying seems so tough to me. I aspire to emulate you.
- Finally, I thank all those who assisted, encouraged and supported me during this research, be assured that Lord will bless you all for the contributions you made.

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Revision History

Name	Date	Reason For Changes	Version

1. Introduction

The Geographic Positioning System known as GPS system was earlier developed as a military navigation system for guiding missiles, aircraft and ships to their destinations. The direct signals were useful for measuring and calculating the user's position anywhere on the earth surface. However, the reflected GPS signals called as a nuisance factor for navigation have the capability to be used for numerous secondary applications e.g. altimetry, remote sensing and measure wave height of oceans etc.

In year 1993, an ability to use reflected GPS signals coming back from the surface of earth was introduced by the European Space Agency as a new opportunity. Later on more scientists worked in the same line and published many research papers and journals. In the publications, most of the scientist has discussed various methods used for the collection of data and also its use for extracting information from it. They also focused on the average height above the sea level, wind speed, wind direction and also waves of significant heights. The calculation of moisture content in the soil, bi-static imaging, ice reflected waves to identify ice and ice age, its thickness, density etc can also been calculated by the use of such waves.

Under current circumstances, most of the flying machines are using different methods for the calculation of their altitude. Efforts will be made in this project to design and simulate Altitude calculation using freely available GPS signals i.e. by comparison of directly received signals and surface reflected signals. The availability of such device will be permanent in all weather conditions; it will be more cost effective, covert and Inexpensive as compared to conventional altitude meters.

1.1 Motivation

In the field of engineering, the GPS system came up with number of application and huge scalability spectrum. It was not only used for time and distance calculations but the introduction of reflected signals in the field provides in-depth details of the surface. The most popular implementation of the signal processing was found for the improvement of reception of the GPS signals. However, developments have revealed over the period of time that the Reflected GPS waves can be helpful to make certain calculations with respect to speed, time and wind speed etc. The GPS signals or waves when reflected from different types of surfaces like water, soil and different elements present in on the earth surface, every element adds a unique signature to the wave and it is dispersed in different directions due to diffused reflections.

When the GPS signals emerge from its satellite to reach earth surface, it scatters in different directions with maximum contribution. These reflected signals contain data about the time of transmission, type of surface, latitude and longitude information, which will be extracted and will be used for the project. The direct and reflected GPS signals can be correlated to achieve information like distance and height of the reflecting surface. The main objective of the research was to gather two types of waves while in air, one will be directional wave or direct GPS signal measured by a zenith pointing antenna and other received by a nadir mounted antenna for collection of reflected GPS signals. The correlation of two signals will lead us to find out our required results.

This will remain a inexpensive solution for small plans, where the use of barometric meters for altitude calculation is still in production with lots of its conditional limitations while at night time flight or in bad weather under storms.

1.2 Problem Statement

During the study of science and technology, a fact was established that air as a medium contain different type and frequencies of waves in it with distinct features. One identified and continued research side was capturing reflected GPS signals and uses them for Altimetry measurements. This remains the interest to write this thesis and try to extract potential expected results out of them.

1.3 Objectives

The objectives of the research can be explained in following manners:

Understanding scenarios for better reception of GPS signals

Perform detailed literature review and keep focus on earlier methods adapted for getting maximum results

More efficient and purified data collection

More powerful classification of data to find maximum accuracy in GPS signal based Altimetry

Devise a inexpensive method for hardware design to assemble a possible device for small aircrafts.

Design a simulation for the better execution of code/ scenario

1.4 Organization of the Thesis

The thesis has been divided into six (6) chapters. A glimpse regarding chapter contents is presented in the following few paragraphs:

Chapter 2 (Theory Overview):

The second chapter will help in understanding the reflected GPS signals, and their behavior. It will also explain fundamentals of the GPS signaling and will furnishes some account of this incredible system in terms of basic characteristics and signal properties.

Chapter 3 (Radio & GPS Altimetry):

The third chapter furnishes a detailed description of the GPS radio altimetry operations with reference to their execution, waves used, nature of signal etc. A summary of the theory behind radio signal acquisition is furnished with an exhaustive explanation of signal acquisition along with details of GPS based radar altimetry.

Chapter 4 (Literature Review):

The literature review portion will add more value to describe the work done by scientists and researchers in the field of GPS altimetry to improve altimetry operation in the planes. The researchers work has defined new objectives for upcoming researches in the same field. There work will be briefly defined in the thesis.

Chapter 5 (GPS SPS Signal Acquisition & Hardware):

The hardware designed and assembled for the physical realization of above-mentioned GPS based radar altimeter system is explained in the final portion of this chapter. The hardware comprises of a custom made LHCP helical antenna and an electronic device to be utilized for the collection, analysis and storage of real time GPS data. The fifth chapter will establish a base line drawn by the researcher in the field of GPS altimetry with the efforts they have made to do maximum accomplishments.

Chapter 6 (Simulation & Experiment):

The simulation work performed in a software environment has been explained in the sixth chapter. This chapter also provides some insight regarding the experiments performed to capture actual GPS data with the help of custom made LHCP antenna and dual front end GPS receiver. The results deduced during simulations and practical experiments are also included. The findings are supported by different diagrams obtained in a Matlab® environment, when the simulated as well as actual GPS data, captured as mentioned above was analyzed. The results are compared, findings are discussed and any shortcomings are analyzed. Future planning and further improvements to the system in terms of signal quality, computational efficiency and system resolution have also been discussed.

2. Theory Overview

The Global Positioning System (GPS) is an interesting and unique development of current times. Novel applications for it are constantly being discovered and revolution is going on. This chapter provides some insight about this incredible system. The concepts presented, for example, GPS signal structure and correlation theory are vital in order to understand the basic principles of GPS based radar altimeter.

This chapter presents detailed information about the global positioning system (GPS). The methods used for capturing and refining Global Navigation Satellite System (GNSS) transmitted signals was remain in focus to retrieve maximum altimetry data from reflected signals. The more emphasize was on particularly GPS constellations and its future as European civil counterpart, Galileo (1). The concept was build on low earth orbits at an altitude of 400 to 500 km by retrieving signals, which were emitted by multiple satellites and reflected back by the ocean and earth surfaces. By analyzing these signals, researchers were able to compute sea surface height. The C/ A code were also used to find the user location and are referred as a standard position service (SPS).

This thesis not only introduces the information available but it will also emphasize on its applications. In addition, Different techniques for signal acquisition and GPS signal tracking are part of this thesis.

2.1 General Description

The GPS, originally called NAVSTAR was developed as a military navigation system to guide missiles, ships and aircrafts towards their destinations. The program was first introduced and studied in the 1960s, was formally approved for development in December 1973. The first satellite was launched in February 1978 with the full constellation of 24 satellites circle the Earth in December 1993. It is no exaggeration to say that the GPS (Global Positioning Systems) has revolutionized navigation and position location and that all components of the system have reached its full operational capability in the spring of 1995.

The GPS system consists of three divisions. The first division also called as segment consists of GPS satellites in a semi-synchronous orbit. The satellites orbits were distributed in six orbits having four satellites in each plane. The second division known as medium segment has an altitude of 20,200 km from the earth surface and is able to complete its one rotation in about 11 hours and 58 minutes. Approximately five satellites are visible all the time on the clear sky while orbiting around the earth. An emergency system was also introduced during the improvement in the GPS system to cater emergency situations during orbiting. Currently, 32 NAVSTAR GPS satellites are in orbits with the range of launch date of February 1989 to September 2006. The master control station was of primary importance and was established at Falcon Air Force Base (AFB) in Colorado Springs, USA and the monitoring stations (MS) with several ground antennas (GA) at different locations in the world. Some key monitoring stations are situated at Falcon Air Force Base, Hawaii, Kwajalein, Diego Garcia and Ascension Island. The roles are divided in a way that the MCS contains a primary monitoring facility for the segment treatment and control with the responsibility for overseeing and managing satellite constellations.

The third is user segment, which is a small device used to receive, process and decode signals. This device is always a low budget device for performing appropriate functions per requirement.

2.2 GPS Basics

As mentioned before, the GPS network consists of 24 satellites, which orbits around the Earth twice a day. These satellites transmit signals towards earth as per there footprints. Any GPS receiver can lock onto signals gathering from three or any number of satellites to estimate user location. This method is known as **Trilateration** (2). The GPS receiver has to work in a manner that it calculates the difference between the time a signal transmitted from a satellite and the time when it receives at receiver end. These calculations results as finding the exact location of the receiver as well as it can identify speed if the receiving object is on a move. The distance estimation can also be made using same signals with approximate time of reaching destination.

2.2.1 Basic GPS Receiver

The continuous transmission of GPS signals was received by the receiver by using its internal or external antenna. The signals chain is properly amplified to proper amplitude and then down converted to a desired IF output frequency. The digital output stream is generated by an analog to digital (ADC) converter. A basic GPS receiver is composed of an antenna, RF signals chain, and ADC. The digitized signal then passes through various algorithms to utilize for baseband processing. The GPS receiver collects signals from all available satellites in its view. The acquisition of signals defines the reception of signals of a specific satellite. A simple or basic GPS receiver perform acquisition and tracking by its hardware. From the navigation data phase transition the sub frames and navigation data can be obtained. The pseudo ranges as well as Ephemeris data can be obtained from the navigation data.

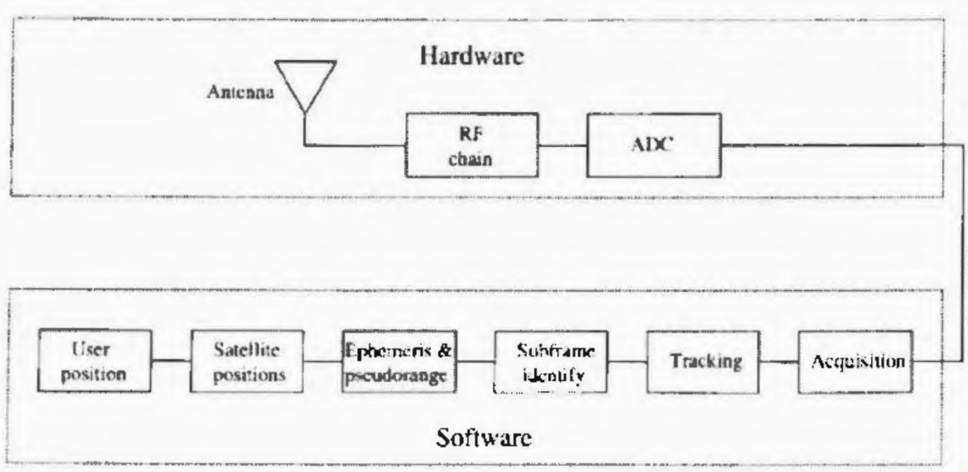


Figure 2-1: A Fundamental GPS Receiver

By obtaining the Ephemeris data with satellite positions, the receiver position can be extracted for the pseudo ranges and satellite positions.

2.2.2 Principal of Working

The GPS satellites contain high precision atomic clocks, which transmits the codes towards the surface. At the receiver side, the concept of time of arrival (TOA), this will further determine position of the user. The measurements provides the time of the signal to reach a known user from an SV (3). The SV position is calculated by trilateration, which is a very well known and easier method to identify user location.

The mathematical method implementation for solving navigation problems is totally dependent on coordinate system of that particular region or country. The representation of the satellite and receiver will be made in the same coordinate system. To detect and determine the orbits of GPS satellites, Earth-centered Inertial Navigation Systems (ECI) coordinate system can be used by considering origin at the center of mass of the Earth. To calculate the position of the GPS receiver, the more effective method is to use a coordinate system that rotates with the earth. Such system is named as an Earth-entered Earth-fixed (ECEF) system. The calculations required for getting latitude, longitude and altitude parameters displayed by any GPS receiver are easy to calculate by using this method. The system has its XY plane, which coincides with the equatorial plane of the Earth. The transformation of the information gathered a physical model is required for describing earth as focus point. The earlier physics model used for the Earth modeling a program of DOD World Geodetic System 1984 (WGS - 84). The model shows the elliptical shape of the earth as well as state of the art-world system datum.

2.2.3 Orbital Concept

The GPS ephemeris not only includes six orbital parameters, but also the time of their effort and characterization of how they travel over instant. By the help of this info a GPS receiver can handle the GPS navigation problems.

Symbol	*Description*
T_{oe}	Reference time of ephemeris data
$\sqrt{a}$	Square root of semi-major axis information
E	Eccentricity

Io	Inclination angle (at time t_{oe})
Ωo	Longitude of the ascending node (at weekly epoch)
Ω	Argument of perigee (at time t_{oe})
M_o	Mean anomaly (at time t_{oe})
di/dt	Rate of change of inclination angle
Ω	Rate of change of longitude of the ascending node
Δn	Mean motion correction
C_{uc}	Amplitude of cosine correction to argument of latitude
C_{us}	Amplitude of sine correction to argument of latitude
C_{rc}	Amplitude of cosine correction to orbital radius
C_{rs}	Amplitude of sine correction to orbital radius
C_{ic}	Amplitude of cosine correction to inclination angle
C_{is}	Amplitude of sine correction to inclination angle

Table 2-1: GPS ephemeris data definitions

Table (2.1) defines the orbital elements used in the algorithms as a GPS receiver to calculate the orbiter state transmitter (XS, YS, ZS) in SCBF number method. In the cover of the GPS satellites there are most advertizing orbits with eccentricities greater than 0.02 and no semi-major axis of about 26,560 km. Another orbital parameters diversify between satellites specified that the plan provides nearly uniform coverage of the entire Connecter. GPS yearbook and ephemeris accumulation transmitted by satellites also allow Kepler osculating orbital elements, which are complemented by "parameters" that we allow the somebody to estimate the Kepler elements with enough truth during periods of the measure between updates of orbiter ephemeris message to perform the needed computing, it is eminent to bonk the motion of turn of the Earth According to WGS-84, the mass range is e = 7.2921151467 x 10 - 5 rad / sec (4).

2.3 Services Overview

The GPS provides two levels of services, the Precise Positioning Service (PPS) and the Standard Positioning Service (SPS). The PPS is the exact position, speed and timing of service to authorized users only. The PPS is primarily intended for military purposes, rather than the GPS accuracy is achieved by using P (Y) code, which has provided both the L1 and L2 signals. The SPS is using the C / A code and is less accurate navigation service. It is intended primarily for civilian purposes and is available for all users, only the L1 frequency (1).

The biggest difference in the two codes is the chip rate. The C / A code were transmitted at a rate of 1.023 MHz chip, while P (Y)-code is transmitted at 10.23 MHz. Unlike the chip rate, it does little to increase the basic accuracy of P (Y)-code, because the difference of power levels (C / A code power is 3 dB higher than the power of P-code) partly compensates for the differential rate chip. The large errors in GPS navigation are an errors caused by ionospheric delay, P (Y)-code is much more accurate than C / A code because the ionospheric corrections can be made by measuring the difference in transmission delay between two frequencies (LI and L2). To improve GPS accuracy for civilian users, an SPS technique called differential GPS (DGPS) is used (5). In this technique, several receivers are used to increase accuracy in conjunction with GPS. The technique involves a comparison of GPS signals, which calculates the position of a solid receiver with its position interviewed for calculating errors between the two positions, and the transmission of these error corrections to other (mobile) GPS receivers. These technologies currently offer the highest degree of accuracy achieved without the use of information outside of GPS measurements. But these techniques require that all beneficiaries of the system follow the differential carrier phase GPS signal, relative to the channel carrier frequency. Thus the carrier tracking phase is necessary to achieve sub-centimeter positional accuracy. This means solving the ambiguity over. However, only works effectively in local areas, usually less than 50 km.

Therefore, the traditional local area network DGPS cannot be used in a variety of applications DGPS area. To this end, Wide Area Differential GPS (WADGPS) and Regional Area Differential GPS (RADGPS) methods have become popular in recent years that can be overcome disadvantages associated with conventional DGPS method.

2.4 Theory of Operation

The GPS satellites channelize two vector frequencies called L1 as primary frequency at 1575.42 MHz and L2 as secondary frequency at 1227.6 MHz, the GPS sign spectrum is shown in Figure (2.2). The GPS signal uses two different codes for the transmission through direct sequence spread spectrum (DSSS) technique. These codes transmitted by the satellites enable a GPS receiver to judge the transit instant of the signals and make the interval between a satellite and the user. On the transmission of the message, the navigation message provides data to calculate the position of each satellite. Hence the user's position coordinates and clock offset of users can be calculated using an appropriate algorithms. In actual case, a receiver at minimum requires four (4) satellites to get coordinates and solve them in the equation.

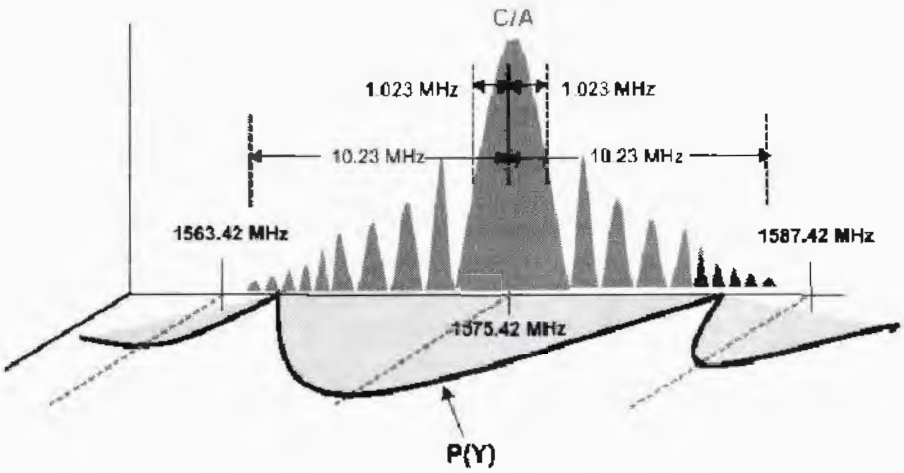


Figure 2-2: The GPS Spectrum

The GPS signal at L1 frequency can be expressed as: -

$$SL1= Ap\ P(t)\ D(t) \cos(2\pi f1 t + \Phi) + Ac\ C(t)\ D(t) \sin(2\pi f1 t + \Phi) \quad \textbf{Equation 2-1}$$

Where SL1 is the signal at L1 frequency, Ap is the amplitude of the P code, $P(t) = \pm 1$ is the phase of the P code, $D(t) = \pm 1$ is the navigational data, f1 is the L1 frequency, Φ is the initial phase, Ac is the amplitude of the C/A code and $C(t) = \pm 1$ is the phase of the C/A code.

2.5 Advancements in GPS

As relation of GPS improvement efforts, several new signals are unsurprisingly included in the GPS signals spectrum to change the quality and completeness of all users time maintaining compatibility with GPS equipment (5) . These new signals are summarized beneath.

L1C (1575.42 MHz):

These signals will be transmitted at higher power level, However they are backward compatible with L1 frequency. One major understanding for the transmission of signal at higher level is to improve its imaging quality and range of transmission.

L2C (1227.6 MHz):

This signal allow the correction of the ionospheric time delay errors as well as it will help in the development of lower-cost, dual-frequency civil GPS receivers.

L5 (1176.45 MHz):

The concept behind the use of this frequency is safety-of-life aviation and this frequency falls in the "Aeronautical Radio Navigation Services" band. These are wider bandwidth signals and will be transmitted at higher power level then current normal signals. This signal will further improve the opportunities for GPS radar altimetry.

2.6 GPS Satellite Signaling

2.6.1 The C/A Code

The C / A code (means Clear / Acquisition) are composed of 1023-bit pseudorandom noise (PRN) sequences at the clock rate of 1.023 MHz for every millisecond. Each satellite gets assigned with a different PRN code, which were selected from a set of two codes called Gold codes. The Gold codes have the tendency of superior autocorrelation and low cross correlation as their properties. The sequences of pseudorandom numbers are very specific and easy to generate by using two feedback shift registers. The two shift registers of 10-bit each are called G1 and G2. They can create maximum length of pseudo noise (PN) codes at length of $2^{10}-1$ = 1,023 bits. The Figure (2.3) shows the C/A code generation circuit diagram. The polynomial and the initial state of the C / A code are as follows in Table (2.2): -

Register	Polynomial	*Initial state*
C/A Code G1	$1 + X^3 + X^{10}$	1111111111
C/A Code G2	$1 + X^2 + X^3 + X^6 + X^8 + X^9 + X^{10}$	1111111111

Table 2-2: GPS code generator polynomials and initial states

As shown in Figure (2.3), the output sequence of the exclusive OR and direct sequencing of G1 and G2 results as a unique code generated for each satellite. The C/A code can only be transmitted on L1 frequency as un-codified signal stream and available for all normal GPS user. The exclusive OR of two shift registers in length results with 1,023 possible gold codes for GPS C/A Code generation architecture. All sequences do not possess low correlation properties. Hence, 37 Gold Code with best possible characteristics were earlier selected for GPS space segments.

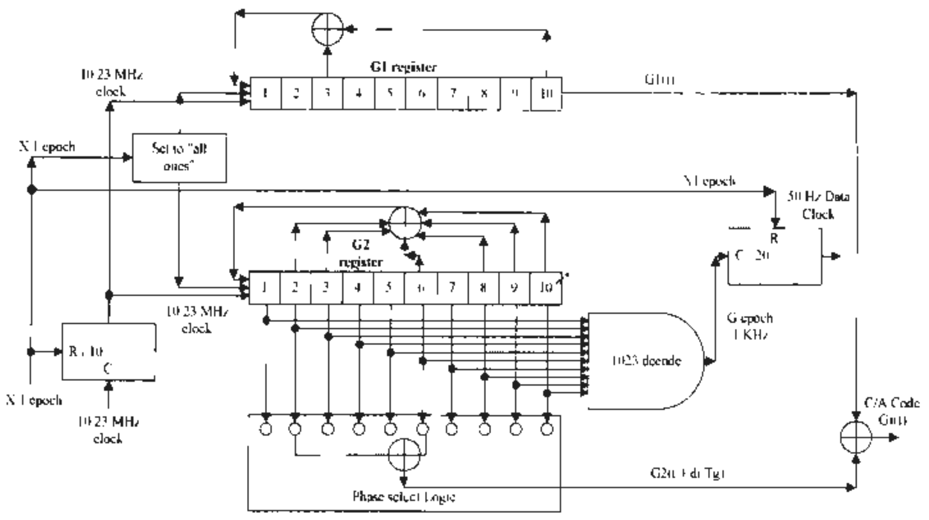


Figure 2-3: C/A code generator

Low cross-correlation sequence is necessary because the GPS receiver at the same time distinguish signals from up to 12 satellites, using correlation techniques. This is an important feature of GPS is an important part of the simulation to identify the target using reflected GPS signals.

2.6.2 Correlation properties of C/A code

The correlation is a product of integration of the received signal with a copy sent to the waveform. It is a statistical process, and above all a certain resemblance. The correlation of the characteristics are used to optimally detect signals in white noise, and are particularly important for the detection of GPS signals that are buried in noise. Such features are available in the receivers to determine the time by comparing the signal received with internally generated copy as per transmitted signal. The time shift remains the highest correlation to measure the diffusion time.

The GPS signal is transmitted based on CDMA and is buried in noise because of low signal to noise ratio (SNR) below 0 dB. Therefore, with correlation time of one millisecond the C/A code is 1.023 Mbps. The theoretical processing gain of 30.1dB or 1023 (10 x log10 (1023)) is possible. So, based on correlation theory, the code can easily be detected even if it is with huge amount of noise.

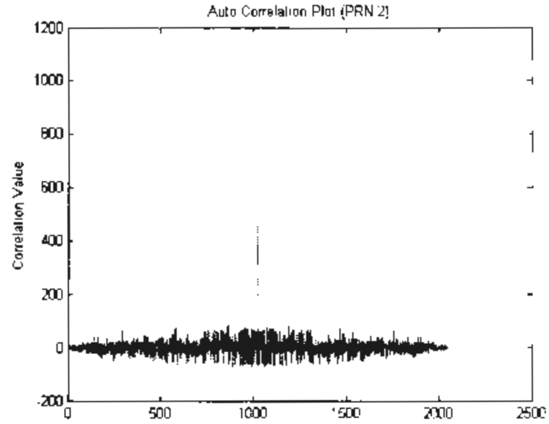


Figure 2-4: Autocorrelation of C/A code

The values generated by the cross-correlation for individual C/A codes are too small and unable to allow from GPS satellites signals simultaneously on the same frequency. It can be seen in Figure (2.5) that the other correlation values are less than the correlation peaks. Secondary peaks in the autocorrelation tract of at slightest 24 dB below the highest peaks. The maximum value is 1023 autocorrelation, which is the number of tokens (equal to 1023) in a set of code C / A. This remains an important property of the GPS signals and contains a vital role in our simulation to measure the distance between reflected and direct signal.

2.6.3 Navigation Data

The key feature of the GPS C / A code is a navigation message. The navigation message contains information used by GPS receivers for the optimization of the satellite signals and performs calculations on stocks and other navigation parameters. In general, the navigation message of GPS is extracted by 50 basis points below C BPSK demodulator/ correlator code (6). A narrow-band communication with a high SNR demodulator input, thus the low quantity of bit errors in the navigation message.

2.6.4 Satellite Signal Modulation

The description of the structure of the GPS signal modulation is stated in diagram of Figure (2.4). The C/A code, P(Y) code and the navigation data can modulate L1 frequency (154 x fo). On the other hand, the L2 frequency (120 x fo) can only be modulated by the P (Y) and code navigation data message, such frequency is known as nominal reference frequency and its equivalence is 10.23 Mhz. The two codes C/A and P(Y) codification as fit as L1 and L2 frequencies were subjected to the flap frequency encryption SA (Selective Availability) (6). The SA delay was old to bound the precision of GPS C / A codification users and has been old since May 2000.

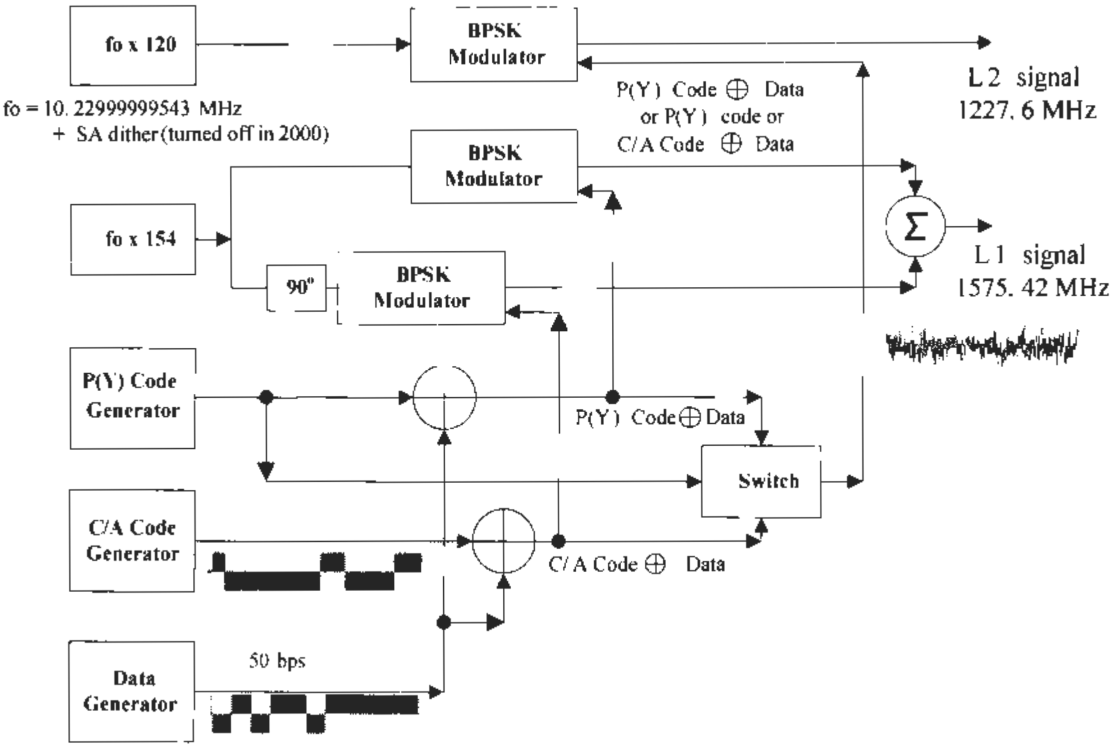


Figure 2-5: GPS satellite signal structure

As described from the above diagram, the combination of C/A and P(Y) code with 50 bits per second data has been done prior to the modulation with L1 carrier. A function of exclusive-OR performs the combination denoted by ⊕ and the modulation is carried with Bi-phase Shift Keying (BPSK) method. The C/A code ⊕ data on the L1 frequency is modulated with P (Y) code ⊕ data in phase quadrature. Figure (2.5) illustrates the method of C/A code data clarifies that the exclusive-OR method is equal to binary multiplication of two one bit values (6).

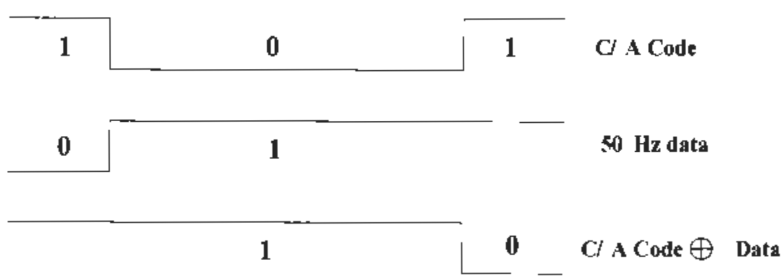


Figure 2-6: GPS code mixing with data

The BPSK model reverses the carrier phase when the modulating code changes from system 0 to 1 or 1 to. The C/A-code spreads the L1 signaling power over a 2.046 MHz bandwidth concentrated at 1575.42 MHz. Each GPS satellite has four atomic clocks that are calibrated against time standards in the GPS control stations around the world. This result in internal reference time and it will be further used by three major segments of the GPS system known as GPS time.

However, it is not cost effective to place atomic clocks in GPS receivers, thus necessitating the use of standard crystal oscillators. Consequently the receiver clock has a clock offset with respect to the satellite and results in inaccuracies in position measurements. Fortunately, a time measurement from a fourth satellite helps in solving the receiver clock offset error called (τ).

2.6.4.1 Doppler Frequency

When an object or a receiver is in motion relative to GPS satellites, the received signal is different from transmitting signal equal to the Doppler frequency offset. The satellite speed is measured from the orbital system model, which is part of the receiver. The frequency changes by moving receiver, the satellite motion of receiver or when the satellite movement is going far away or the Doppler frequency change to zero occurs in the case when the satellite is at closest position with respect to receiver. The satellite motion cause changes in Doppler frequency and it affect both the carrier frequency and the C/A code. The biggest change in the Doppler velocity (DV) over time can be approximated 0.178m/s2. The maximum change in Doppler frequency is,

$$\delta f_{dr}\big|_{\max} = \frac{dv_d}{dt}\frac{f_r}{c} = \frac{0.178\times1575.42\times10^6}{2.99792458\times10^8} = 0.936Hz/s \quad \text{Equation 2-2}$$

This small value allows the tracking loop update process every second. Therefore, it is observed that the satellite motion changes Doppler frequency, which is very low to create a significant effect in comparison to the update rate of tracking program.

2.6.5 Theory of Radar Altimeter

A radar altimeter is a low range radio altimeter (LRRA) device or we can simply say that the RA measures altitude above the surface which is present under an aircraft, spacecraft or any flying object. Such types of altimeters provide the distance estimation from the aircraft to the ground to measure its height. It is an opposite concept to any barometric altimeter, because barometer outcomes the distance above a pre-determined surface line typically sea level. The basic fundamental of RADAR is quite understandable but its theory details are complex due to calculations involved in it (7). The effort and action of basic radars systems relate a broad reach of disciplines such as construction activity, heavy mechanical and electrical technology, high power microwave work, and high speed signaling and data processing techniques. Many laws of nature are of a greater importance here.

The radiated electromagnetic energy has made it possible to measure ranges, distances, and other wireless detection requirements.

Figure 2-7: Radar principle: The measuring of a round trip time of a microwave pulse

1. Electromagnetic waves reflection

   The electromagnetic waves posses the property of reflection from the leading surface and if these are captured back at the place from where they were generated. It is quite easy to understand that any obstacle in the line of waves propagation direction.
2. The electromagnetic wave travels in the air at a fixed speed approximately the speed of light at 300,000 km/sec. Therefore this fixed speed of wave and its bounce back after hitting any air bourn object will be used by calculating its travel time to identify the distance from the origin to the flying object.
3. The atmospheric and weather condition effect on the wave is very low due to its straight line movement in very high speed. These waves can be used to through in all directions due to special design of antennas. Therefore, the direction in azimuth and its distance from the surface can be determined.

These fundamentals are implemented in the radar system for the calculation of the distance, direction and the elevation of the flying object. These principles can basically be implemented in a radar system, and allow the determination of the distance, the direction and the height of the reflecting object (7). A detailed account of the effect of atmosphere and weather will be discussed later, however temporarily we ignore its effect for the calculation of distance, direction and height.

3. Radio & GPS Altimetry

This chapter will furnish details regarding the GPS signal acquisition and altimetry. It will define the GPS altimeter operations by furnishing the basics. The contributions made by researchers as well as their results have defined a road map for future developments. The purpose of this thesis is to estimate potential in reflected GPS signals and there utilization for Altimeter operations.

3.1 Altimeter Measurement System

An altimeter is an elevation description system especially useful for mountaineers, skydivers, aviators, satellite, and some others. The altimeter has a simple objective to give estimated height to the user from the sea surface. It works using two basic ideas; one is to perform calculations using measurements of local air pressure by barometer and second is by wave reflection estimation in radar system. Since the inception of barometric technique, a small mercury column was attached with an open mercury reservoir to measure atmospheric pressure (8). Any minor change in the air pressure can be easily detected with this device. This instrument is known as a *barometer*.

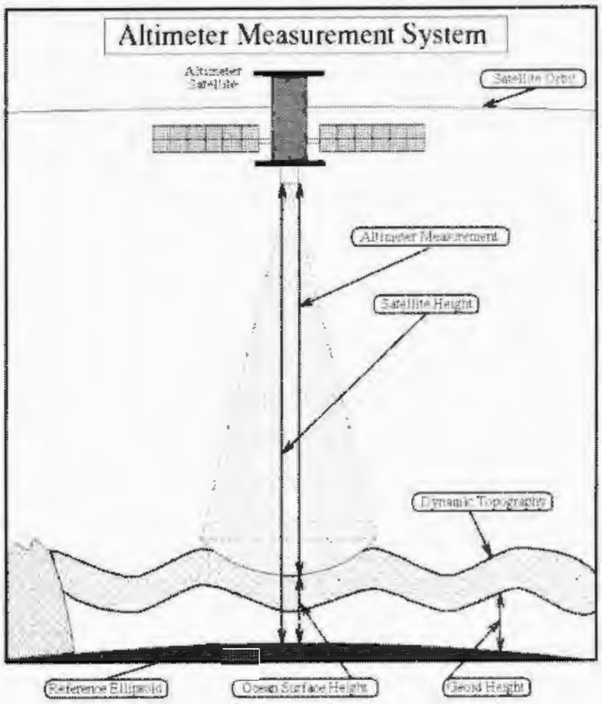


Figure 3-1: Altimeter Measurement System

At altitudes relatively nearby to sea, air pushing deviates consistently with raze. Every 27 feet (8.23 m) one ascends above sea height, air pressure rises by almost a millibar, each unit of pressure can be measure in inches of mercury. Therefore, a barometer can work as an altimeter. The newer barometers are independent of the rising air pressure with increase in altitude as well as they are more correct then before (8). For high-altitude aerospace programs, and in any domain in which greater reliability is desirable, a radiolocation altimeter is utilized.

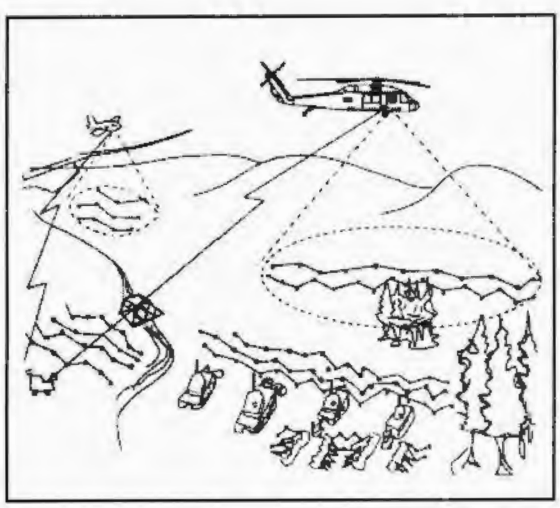


Figure 3-2: Altimetry Uses

A higher performance radar altimeter achieves its perfection by calculating the trip distance of the wave from the terrain to the flying object. This makes a difference in perfect reading in comparison to the barometric measurements at higher altitude. One feature of radar altimeters is to identify ground natural changes in terrain like presence of mountains and sea. Altimetry has been used to reassert the workaday extant of uncommon "panic waves", ocean waves various times higher than normal waves. They are also utilized in all types of aircraft routing and kind it affirmable for aviators to land their air carriers intimately. The highest mountain ranges have been precisely assessed using an altimeter.

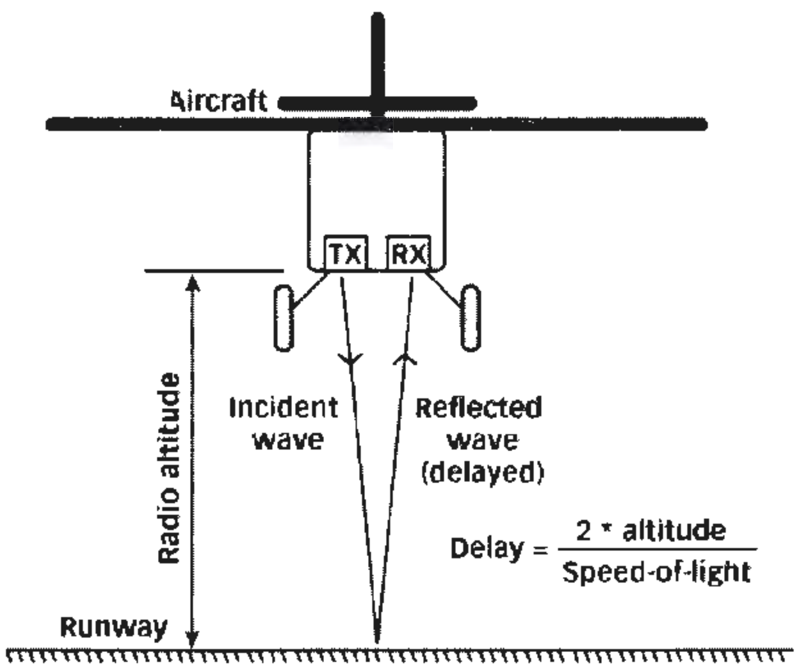
3.2 Radar Altimeter

An altimeter (9) can measure altitude more precisely; it uses the time taken to capture a signal after return from the terrain reflection. The commercial and military crafts use such types of altimeters to land in perfect manners. The flight height measurement is the most delicate feature of the altimeter by warning the pilot to fly at a perfect height mentioning the low level or rising above the terrain. Measuring low altitude give military war pilots to fly low and hit the targets more accurately. It can also be utilized in UAVs and other light aircrafts as ATLS (Automatic Take off and Landing) sensor.

Aviation radio altimeters are typically uses 4.2 to 4.4 GHz (10) band of frequency on short ranged FM radars. Their principal use is instrumented approaches and landings of sizable mercenary aircraft. The truth and determination of air altimeters are generally restricted to a few meters because of the modest bandwidth of 200MHz to 4.3GHz frequency bands. This exactitude is thoughtful sufficient for an operation in automatic landing a jet aircraft to large commercial flights. Most organization efforts went into developing certain altimeters, which allows alter operation of two or triad instruments in the discrete displace and receive antennas even a major effort has been invested in the development of a radio altimeter with single-antenna. Altimeters may not consider very useful for moderate aircraft, because that commonly works for Visual meteorological conditions. The smaller jet require more accurate altimeter for landing since there speed of approach is relatively three to four times smaller.

3.3 Radio Altimeter Operation

In normal flights, aviation radio altimeters are used which is short in distances, low in power and continuous in manner of wave radars. The usually uses two distinct transmit and receive antennas shown in Figure 3.4. One major reason of using transmit and receive antenna is the wave propagation delay short time span, which is not difficult to handle by a single antenna (10).



1. A radio altimeter uses separate transmitter and receiver to differentiate received reflected waves from the original transmitted waves.

Figure 3-3: Principle of operation of a radio altimeter

For more precise and accurate readings, it is evident that the placement of receive antenna for the reflected waves must be done in perfect manner so none of the direct waves reaches it (10). The placement of both antennas should be a distance from each other to avoid interference between them. Although by using electronic filtering crosstalk, it helps designing of radio altimeter antenna with minimum maintaining efforts. The radar frequency modulation is used in most of the aviation radio altimeters. The deviation of receive frequency from the transmitter frequency is due to delay in received signals. If the rate of change of transmitter frequency is constant with the delay then the height is directly proportional to the calculated frequency difference between receiver and transmitter. The conventional design of FM radio altimeter system is shown in Figure 3.2. The triangular wave form scanning and two slopes are mostly used to measure height to compensate for Doppler shift due to vertical velocity of the flying object. The scanning speed is mostly in-between 50 Hz and 300 Hz, however upper limit are defined by the receivers thermal noise and the lower limit remains an opportunity for altimeter to eliminate Doppler Effect.

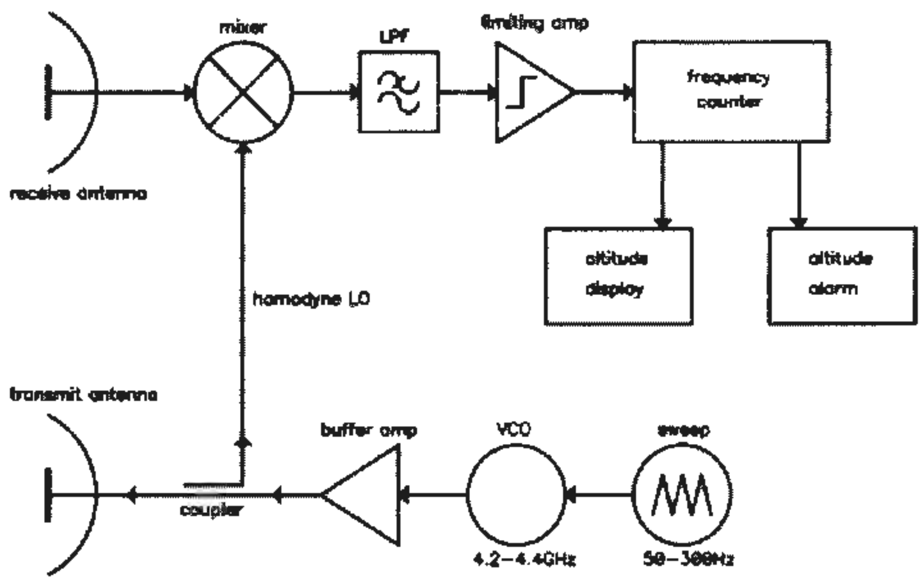


Figure 3-4: Conventional FM radio-altimeter design

The frequency band of 4.2-4.4GHz is used in most of the radio altimeters. The 200 MHz is available only in the middle of about 150 MHz is commonly used. The 4.3GHz frequency band (7 cm) is suitable for adjustment between surface roughness and available bandwidth. The range of transmission power is 10 mW (10 dBm) and 500mW (+27 dBm). The directionality buttons as well as transmitting and receiving antennas are only about 10 dB to operate the radio altimeter, moderate height and tilt of the machine (11; 10).

The receiver is a unique design based on the difference between receiving and sending. The difference of frequencies is less then 1MHz. The transmitter signal's part is used for local oscillator and a receiver. There are some models of radio altimeters which are only used for cross talks between receiver and the transmitter. The received signal first filtered and then amplified. A frequency counter device with different altitude indicators is placed for different alarms while change in altitudes. One key factor is to subtract aircraft installation delay caused due to the electric cables connecting both side antennas (10). The accuracy and resolution of the radio altimeter lies in RF bandwidth shown in Figure 3.5. During the flight if changes occur in measured height, the pattern shifts and different new oscillations were formulated between two adjacent values.

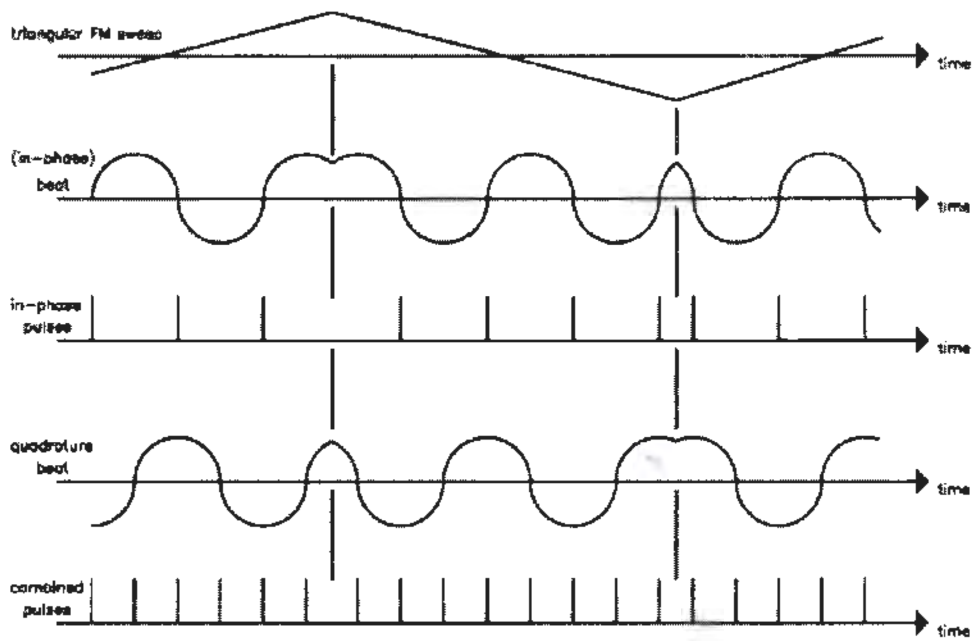


Figure 3-5: Accuracy and resolution of a radio altimeter

The improvement in the accuracy and resolution of the radio altimeter has different approaches; one simplest approach is to increase scanning frequency to 400MHz [11]. Another better method is to add some low frequency (about 10 Hz) wave sweeping the main triangle triangular dither. Thus, the oscillations between two adjacent values are an average of various measures, but little additional bandwidth is required for activation. One way is to add another receiver channel in phase quadrature. It will double the number of transition and will improve the results by factor of two. An altimeter is height calculation device from a fixed level, and it can also be measured by using atmospheric pressure because the lower the altitude the greater the pressure. The barometer with nonlinear calibration for the altitude calculation by using air pressure, it is known as pressure altimeter or barometric altimeter. Most of the air craft's are using pressure altimeters for height measurements.

There are two types in radio altimeter operations.

3.3.1 FM Type Radio Altimeters

An ultra-high frequency transmitter that is frequency modulated sends out waves of a frequency that varies linearly with time. The radio energy is transmitted from an antenna located on the under surface of the airplane and is beamed towards the earth (12).

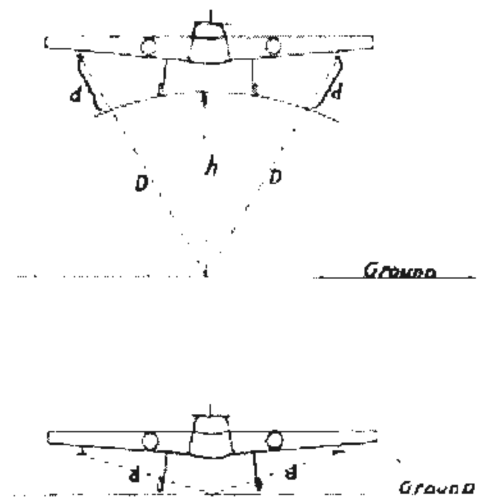


Figure 3-6: FM Altimeter for High Altitude

A direct signal is coupled from the transmitter to the balanced detector. The function of the balanced detector is to heterodyne the direct signal from the transmitter and the reflected signal and to produce a resultant beat frequency at its output. A further function is to minimize in the output the effects of amplitude modulated signals received on either of the input voltages. Such amplitude modulation will occur due to the selectivity of the coupling loops and the line between the transmitter and the detector (12). The output of the detector is an audio signal equal to the instantaneous differences among the frequencies of the signal leaving the transmitter and when the signal returns and is proportional to the height of the airplane above the terrain.

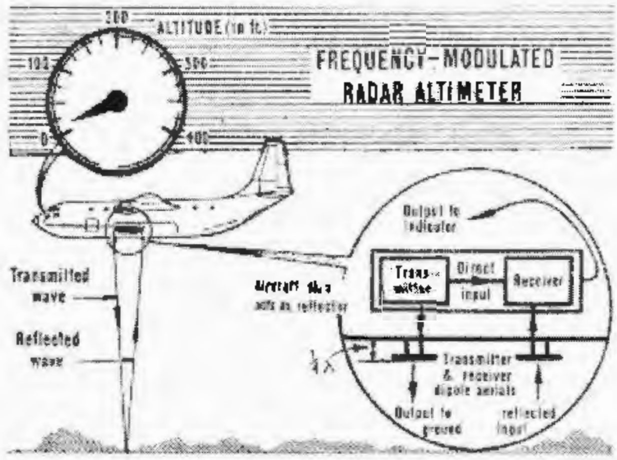


Figure 3-7: Typical FM Radar Altimeter Layout

The f-m altimeter is designed to measure altitude accurately at low altitudes and has a small fixed error. Since there early development in the field of altimetry, they were used in small plans and air-balloons.

3.3.2 Pulse Type Radio Altimeters

A pulsed-typed radio altimeter is designed on the principle of radar for measuring absolute height of an airplane above the terrain below. In principle radio frequency energy plus is transmitted towards the earth and the time which elapses between the transmitted pulse and the received pulse is measured (12). Where the velocity of propagations of electrometric energy is known and is a constant. The time is proportional to the height of the aircraft.

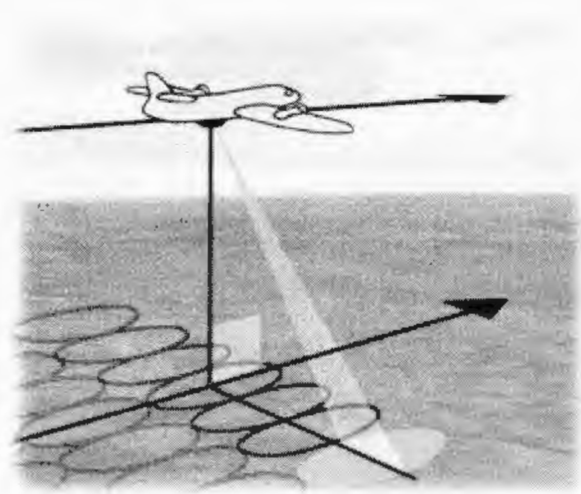


Figure 3-8: Typical Pulse Modulated Radio Altimeter Layout

This system actually measures the absolute altitude and has been implemented in various aircrafts and jet fighters. The objective for such system is the advancement of aviation as a mean of transportation and security under all weather conditions both for day and night operations. One particular requirement of time is to control airplanes at various altitudes of flights has accelerated the need for reliable absolute altimeter. A major disadvantage with aneroid altimeters was that they cannot indicate absolute height at low altitudes. If the barometers pressure and temperature varies, results a large error. This could be the reason of a major air craft accident. Hence, aneroid altimeter is not entirely reliable for blind landing use.

3.3.3 Comparison of FM & Pulsed Typed Radio Altimeters

A close comparison of these two types has been made and unfortunately, a pulsed altimeter and FM altimeter having the same specifications. In general, either system may very well be adapted to reliable measurements of a few feet and upwards of altitude. If the device is useful for the pilot of the object, during landing operations the radio altimeter must measure altitude in the close vicinity of the earth (12). The most important service of the altimeter is to furnish a pilot data of the altitude of an airplane when the plane is being operated near the ground, whether the ground is a landing field or a mountain peak.

Both systems require separate transmitting and receiving antennas. In FM altimeters placing two antennas remain mandatory for a frequency transmission and reception. However, a single antenna could be used in pulsed-type altimeter by blocking the receiver during the transmission of the pulse. The best recovery time in a receiver is several micro-seconds. By calculations, one micro-second is equal to 500 feet in distance from the ground. Hence, the minimum altitude measurement is too high for landing an airplane or for any practical use of the gear over mountain terrain.

Separate antennas gives rise to thick errors which of course are inherent in both systems. These errors are significant in low altitudes in comparison to higher altitudes. As two separate antennas are installed (12), so the path length of each antenna to a point directly under the center line between antennas is different from the true altitude. When an airplane is climbing after takeoff the path lengths increases slower than the true altitude causes an altimeter to read low.

The FM system best perform from zero to 300 feet in order to minimize this error. The low range limit of the pulsed-type altimeter is too high for this error to be significant.

The antenna used in both type of systems are dipole where earth surface acts as a reflector. The characteristics patron of such antenna is rather broad pattern. The indication could have lost when the airplane banked into a turn or they would be misleading when the airplane was in diving or climbing position.

In the pulsed-type altimeter the minimum height measurement is a distance equivalent to the pulse width, and any effect of coupling would be to block the receiver if the coupling energy were too great; thus, the minimum measurement would be even greater. It is very likely that the reading of the altimeter would be the distance to the reflecting object rather than the measurement of the true altitude of the airplane because of the rising gain characteristic of the amplifier in the f-m altimeter.

It is very likely that the reading of the altimeter would be the distance to the reflecting object rather than the measurement of the true altitude of the airplanc because of the rising gain characteristic of the amplifier in the FM altimeter.

3.4 GPS Altimetry

The Global Positioning system (GPS) earlier developed for the purpose of navigation only used for earth remote sensing and atmospheric probing since seventeen years. Now days, the scattered off signals from the surface of ocean and captured by flying air craft or space borne receiver for doing altimetry and scatterometry operations (11) become more effective. The two major benefits of GPS signals are; the satellite signal is transmitted in all direction with all times availability in every weather conditions and secondly, its receiver technology is very inexpensive in comparison to remote sensing devices. The interesting aspect of the analysis involved remote observation of the surface reflected GPS signals to investigate the conditions of the polar sea ice.

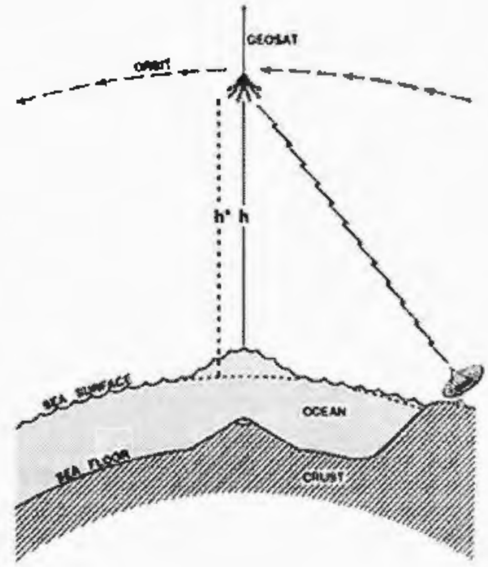


Figure 3-9: How GPS Works

The applications are particularly useful because of the environmental characteristics of these regions. In situ and aerial mapping of sea ice conditions presented special problems for conventional instrumentation due to the inaccessible and hostile environment, frightening levels of visibility most of the year and persistent cloud cover. Instead, the GPS signals are available around the clock and can be saved for later applications of signal processing.

3.4.1 Concept and Definition of GPS Signal Acquisition

The theory works as follows, A GPS based radar altimeter for calculating surface height at sea will work as a space borne GPS receiver. The receiver receives signals directly from the satellite and also gather echo of the same signal after reflecting back from the sea surface. By performing the calculation on the two types of signals, we are able to calculate the sea surface height. The receiver senses the reflection from the angle of incident of waves from the ocean surface. Therefore, the system will better work on minimum angle of incidence up to 10 degree. Hence receiver will be able to get strong signals not more than ten in number to avoid unnecessary computations. The reflected signal from the ocean surface was also averaged (from 1 to 10 degrees) to lower down the noise. Mainly this concept is weak due to its accuracy; the height at angel of incident of 10 degree is some meters with sea surface error. To avoid this weakness, more reflected signals from single point of incidence are require for reflected data. This is totally dependent on the presence of satellites in the GNSS constellations; however GPS constellations does not have a significant growth. On the other side, a new GNSS system named as Galileo is in process of development by the European Space Agency and soon it will be seen among other constellation. The accuracy standard achieved at the maximum level at any time would be 30 centimeters rms (13).

3.4.2 GPS Altimetry Constraints

Following are the major constraints required by any GPS receiver to perform calculations:

1. Minimum three satellites locations to lock in with object to be identified

2. The distance of each satellite from the object

The receiver focuses on the high frequency signals received from the GPS satellite. For more perfection in calculation, more satellites are required to be locked in the object required to be identified with more strong frequencies received.

4. Literature Review

The studies performed by number of researchers has shown that the Global Navigation Satellite Systems (GNSS) including the Global Positioning System (GPS), Global Navigation Satellite System (GLONASS) and the European Satellite Navigation System (Galileo) has the potential obtain the surface information, the process is called GNSS-Reflection (GNSS-R).

Since the inception of GPS technology in (1970), it has been used in several unique manners and became an essential part of big industry. The data achieved from different geodetic quality receivers for monitoring of earth spin and the shake of the Earth on its axis. Most of the geo scientists use GPS data for global warming and earth shifts estimations. The preciseness of the GPS mostly relies on antenna accuracy up to a centimeter. All radio signals emitted from the GPS satellite must pass through layers of ionosphere and atmosphere to finally each earth surface. While passing though the ionosphere layer, signal retrieve water level information from the air molecules of troposphere for moisture forecast as well as provide electron density for space weather studies. Evaluation of these and other demonstrated indicators supports great guarantee for calculating beach conditions, ice age (14), vegetation parameters, and moisture in soil from GPS satellite signals.

4.1 Initial Research Regarding Altimetry

An altimeter can be described as an instrument used for the vertical distance calculations from a fixed point as well as it is used in planes for altimetry operations. Louis Paul Cailletet (1832-1913), a French physicist who first time ever invented altimeter and high pressure monometers. The Cailletet, who (15) installed a 300-m/985-ft high manometer on the Eiffel Tower.

A comparatively accurate approach was using barometric measures to find the height and other respective calculations of the object. In 1928, German inventor Paul Kollsman made a revolutionary invention and provides aviation with World First accurate barometer. The invention is also known as "Kollsman Window".

A customer barometric scale window is provided in sensitive altimeters, which is used for the adjustment in altimeter settings for altitudes. The open source of operation for a barometer is its static pressure. The air became strong at sea level or low height than the pressure at height.

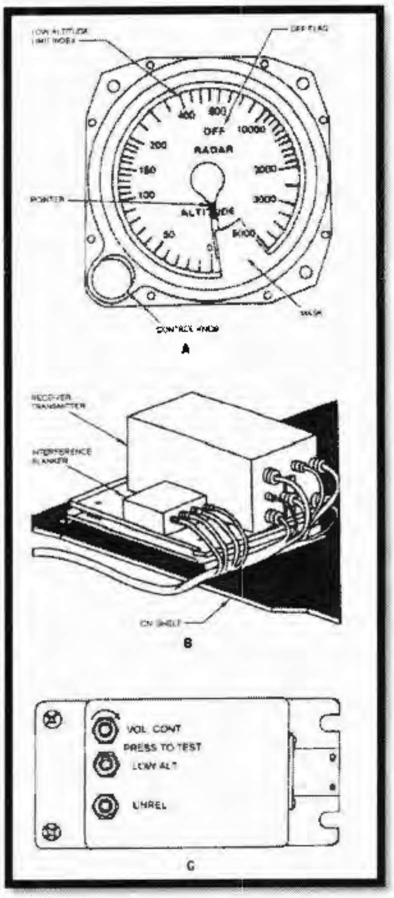


Figure 4-1: Basic Altimeter

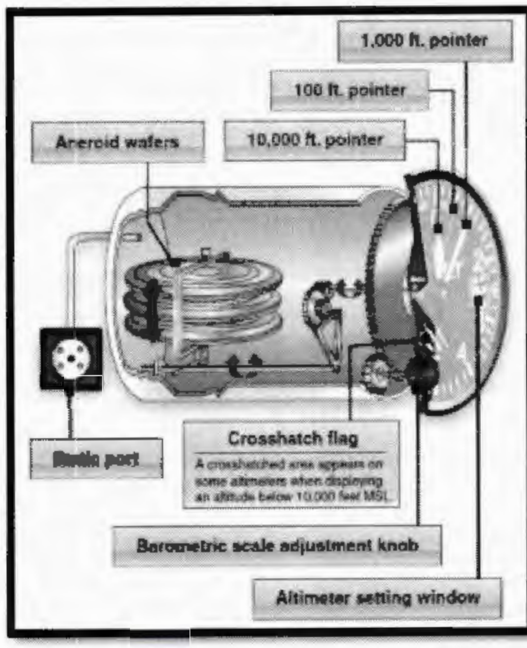


Figure 4-2: Kollsman Window

This creates differences at various levels indicating changes in the altitude of the aircraft. After some time, another type of barometers reached the market having an adjustment knob placed at the bottom for manual adjustment of the air pressure. This is known as barometric pressure setting window or "Kollsman Window". In 1929 James "Jimmy" Doolittle agreed to try integration of Kollsman's altimeter with a gyroscopic, artificial horizon gauge (16) , a ground radio based navigation station for communication for air craft position and cook pit displays as in Figure 4.3. This remain historic achievement of" The first blind flight" using only devices.

Figure 4-3: Advance Kollsman Version Pilot Interface

The change in air pressure of the aircraft can easily be understood as described in Figure 4.4.

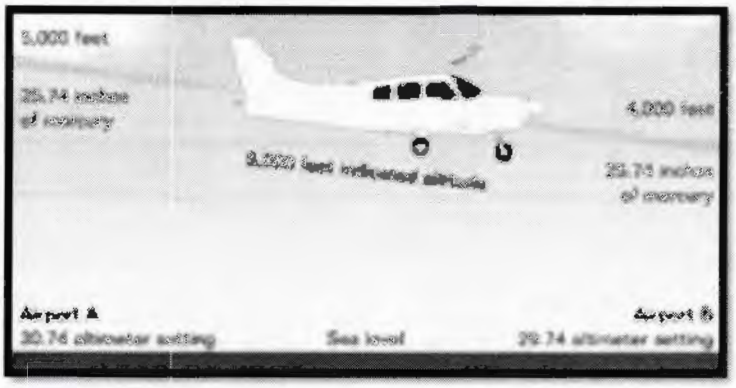


Figure 4-4: Aircraft from High pressure to Low Pressure

The change in temperature can be viewed in Figure 4.5 (17).

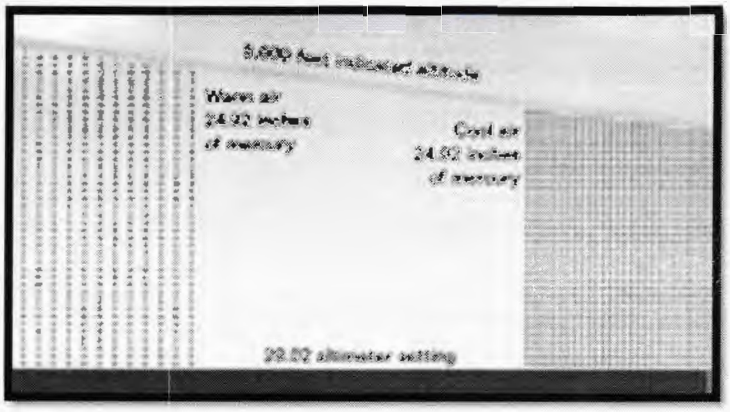


Figure 4-5: Difference in Temperature Effects

The scientist kept their focus on the accuracy of the altimeter for different weather conditions and then finally first Kollsman All Weather Window® EVS was invented in 2001 to give new capabilities for commercial flights, jets and other military uses (15). Now days, the Kollsman EFVS equipped planes can perform excellent landing, taxi before takeoff or after and also can takeoff in total darkness, rain, fog, snow and other less visibility weathers. Such technology achievements have increase flight safety as well as operational delays.

An ordinary plane only contains a barometer inside for the calculations of the aircraft altitude with respect to the air pressure. The table 4.1 is the standard calculations made in terms of altitude translation from pressure in inches of mercury and temperature as degrees of Fahrenheit.

[redacted]	Pressure	Temperature
[redacted]	29.92	59.0
[redacted]	28.85	55.4
[redacted]	27.82	51.9
[redacted]	26.81	48.3
[redacted]	25.84	44.7
[redacted]	24.89	41.2
[redacted]	23.98	37.6
[redacted]	23.09	34.0
[redacted]	22.22	30.5
[redacted]	21.38	26.9
[redacted]	20.58	23.3

Table 4-1: Atmospheric pressure

Weather changes that affect temperatures and air pressures cause the complications in use of altimeter (17). This is why an aircraft's genuine top above nasty sea indicator is its even altitude while what the altimeter says is the indicated elevation.

4.2 Research regarding space based altimetry

The revolutionary concept reaches the approach of Radio altimeters. The first radio altimeter was invented in 1924. Another approach of using FM radio waves was used during the period of 1938 and then presented in New York by Bell Labs. The principle of working for this device was the bounce of signals from the ground and showing up pilot the altitude of the aircraft.

The altimeter seems identical to the planes radar system, but require height precision are of many times greater importance. The TOPEX/POSEIDON altimeter bounces radar pulses off the sea rise and measures the moment it takes the signals to acquisition to the satellite. A microwave radiometer will rectify for any errors in the time delay that is caused by water vapor in the line through the atmosphere (18).

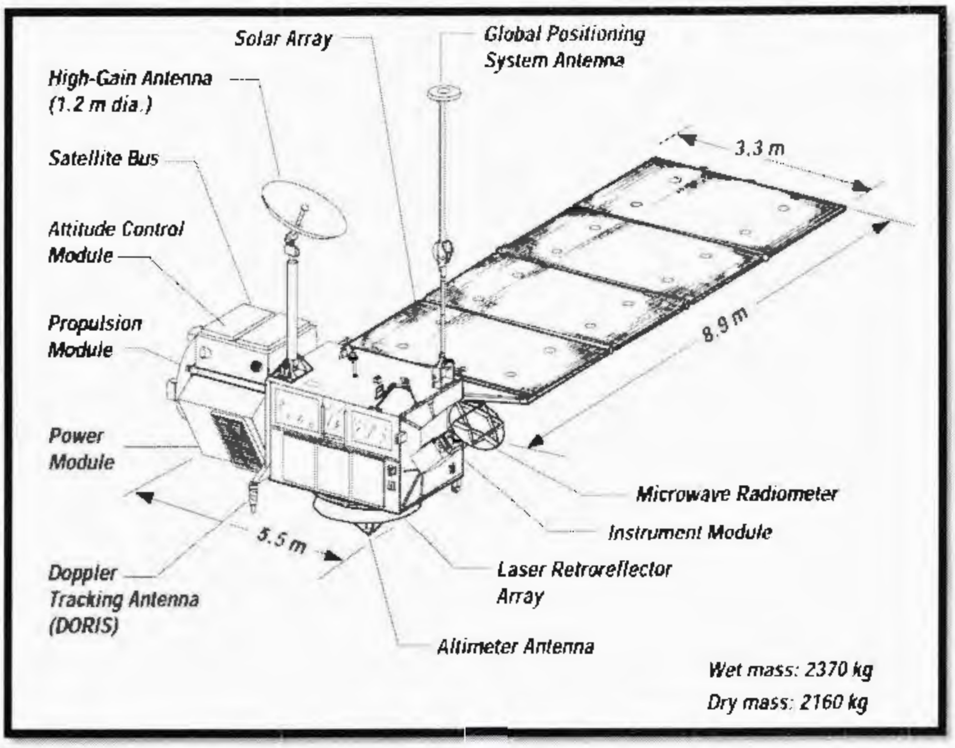


Figure 4-6: The TOPEX/POSEIDON SPACECRAFT

In later stages, the researchers started their work on GPS signal and estimated their potential for acquiring altitude as well as other required parameters for the aircraft. This approach dealt as *GPS altimetry.*

4.2.1 Altimetry 1970 - 1980

Later in the era of altimetry from 1970 – 80, great developments were made for the RADAR accuracy for altimetry system (19). The Skylab (1973) a space observatory with mans, they carried the Microwave Radiometer/ Scatterometry Device/ Altimeter and they has experimented on the sea floor features for the first time. This became a very successful experiment with millions of real data for different nature of experiments.

The GEOS – 3 (1975) was released into the space and it carries an Altimeter, laser reflectors, a Tranet beacon, and satellite-to-satellite tracking systems. This was a very confidential project designed for the improvement of air – ground and sea – ground missiles efficiency by using GPS signals and Lat-Long (19). The data acquired by this experiment was stored and kept away from Non-US investigators and scientists. However, in collaboration with a French team all calculations were made successfully.

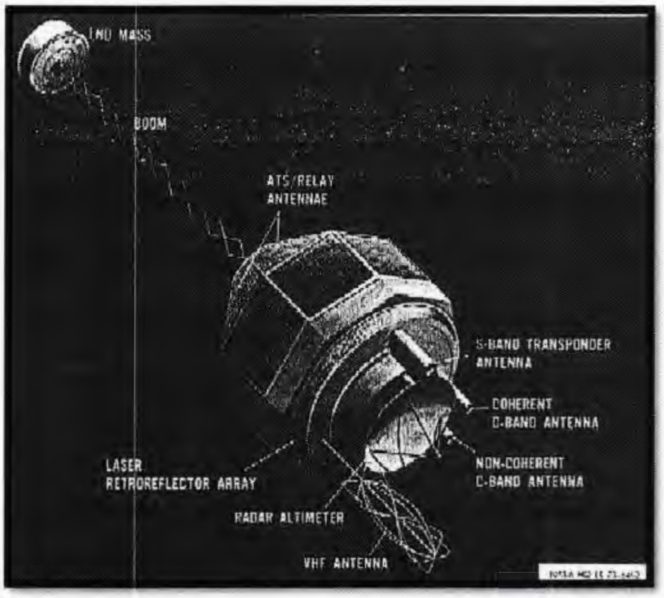


Figure 4-7: GEOS-3 ALTIMETER GEOPHYSICAL DATA RECORD 1975-1978

Seasat (1978) was the first oceanography satellite dedicated for the measurements of very important ocean surface. In particular, Seasat carried an accurate altimeter, laser reflectors and a tranet beacon. It worked for 100 days in the space and it laid the foundations of ocean satellites to new generations (19). The data acquisitioned by the satellite was freely distributed among the scientist and researchers all over the world including all satellite users, Europe groups, a step towards new European Oceanographic satellites.

Figure 4-8: Seasat (1978)

4.2.2 Altimetry 1980 - 1990

In 1985, US government launched another US Navy satellite. This satellite plots the deflection vertically at sea on grid points. The data acquisitioned by this satellite remain a government secret property. In later stages, the satellite captured lots of ocean data for further analysis and also helped in getting true coordinates to get maximum accuracy in Altimetry of airplanes.

Figure 4-9: Geosat 1985

The concept plan for the European Remote Sensing Satellite starts within ESA after the launch of ERS 1, 2 in 1991 (19). The ERS 1 was approved by the member's states as well as by Norway and Canada on 28th October 1981. The altimetry measurements for the study of winds and waves, and the PRARE (Precise Range and Range-Rate Equipment) orbit determination system. The orbit of the satellite was modified to draw first altimeter height map for marine Geoid. This resulted in great accuracy resulting in a greatly enhancement capability of ocean dynamics.

1. The accuracy of orbit of Topex/Poseidon created space for the orbits of these SV's to be computed more precisely.

2. The height of Geosat and the ERS SV's managed the altimeter measurements at higher altitudes.

3. The high end grid formulation of altimetry data from three SV's allowed creation of ocean map giving a feel of presence everywhere.

Figure 4-10: ERS 1, 2 in 1991

4.2.3 Altimetry 1990 and Onwards Advancements

With the passage of time, the requirement now days, the altimeter is used for the many services mainly the determination of:

1. Terrain/Obstacle Clearances
2. Accurate Cruising Level
3. Traffic Avoidance
4. Required Minimum and Maximum Altitude

A single altimeter device may not be able to find out all these parameters but their different types help a pilot to get required data sitting in cockpit of an airplane. It is important for a pilot to know, flying height of air craft from ground, with knowledge about mountain tops and ground stations with towers and tall buildings. Most of the time, a pilot has to be aware of these major problems. A plane that went in to deep, dived and get the same altitude again has the utmost thrill. The radar remains the only reliable source in the plane to know about the exact height for such actions other an ordinary altimeter keeping in mind the expensiveness of the radar devices.

An effort was made in the early months of year 1991 (20). Over-ocean radar altimetry joined with precision orbit determination (POD) and then the calculations from the sea surface to the SV's center-of-mass to gather the topography of the ocean surface. The radar altimeter provides one factor of this measurement, i.e., the distance to the SV's from the sea surface. The mission objective was to measure sea level in a way that allows the study of oceans dynamics. with the calculations of mean and variable surface geotropic currents and the tides of the ocean.

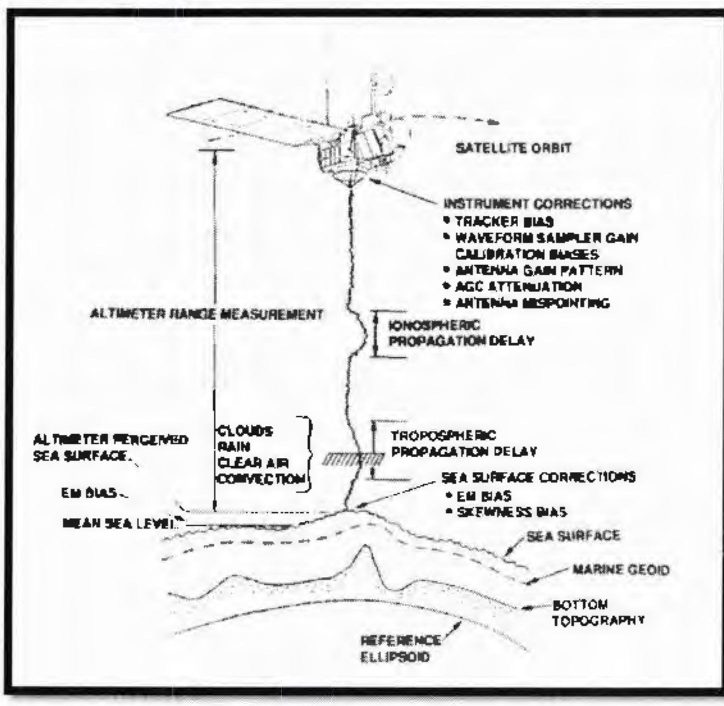


Figure 4-11: The altimeter range measurement and corrections

The mile stone of finding the altimeter range measurement and corrections was tried to obtain using descriptions given in the Figure 4.12 above. It schematically shows the geometry measurements (20). The altimeter designed for altimeteric wave reflection from the sea surface and the characteristics returned in waveform created by the altimeter electronics.

The GPS equipment for remote sensing and altimetry is usually comprised a front end to receive RF data which are then converted to the IF to perform signal processing in the software field. To make a comparison of modern software acquisition data receiver, the devices developed by various institutions and groups have been studied. In the beginning an initial hardware design for capturing reflected and direct signals with its use for altimetry and a concept of remote sensing application was presented in (21). Its shapes like a 3 channel GPS reception device and was tried on the Zeeland Bridge in the Netherlands. The device uses three channels antenna for the reception of GPS L1 signals in frequency amplification and the directed received I/Q demodulation on synchronous sampling rate of 20.46 MHz. The results were encouraging and the proposed future work includes improving the arrangements for providing real-time signal processing algorithms and improved data to minimize bias and best estimates.

The system used by the researchers consisted of two small GPS antennas, a GPS receiver as amended, processor, data recorder and cables. The modified GPS receiver is used to measure the correlation effect on the values of delay and Doppler shift by a nadir pointing antenna LHCP. The main measure was received power from a reflected signal to many delays and Doppler values.

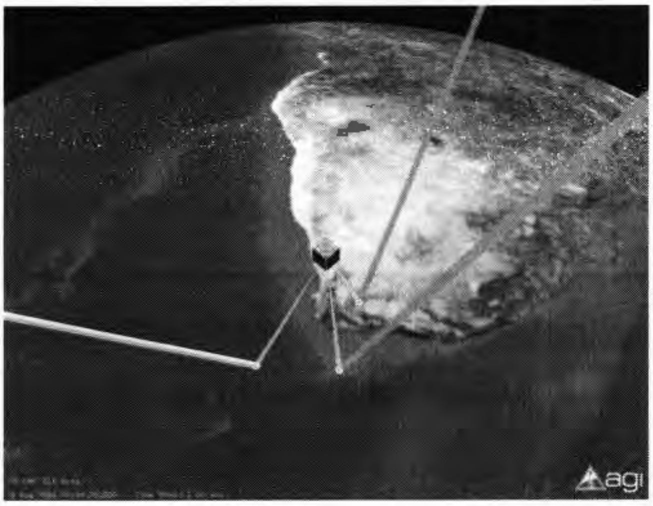


Figure 4-12: Bistatic reflection geometry for signals from three GNSS satellites received in LEO

UK Disaster Monitoring Constellation (UK-DMC) satellite was launched in October 2003. After that it was possible to test the follow-up signals reflected from low earth orbit. UK-DMC satellite is small in size as well as inexpensive SV, and was built at Surrey Satellite Technology Ltd. It provides images every day in various applications, including the monitoring of global disaster. So far, the results of this experiment showed that it is a viable technology with remote sensing of sea roughness and considers the opportunity to make useful scientific calculations of a number of other researches, including the land application of ice and sensor.

Another approach for the measurement of altimetry was presented in year 2000 by an American firm with JPC laboratory, California institute of technology (22). They had presented the first ocean-altimetry measurements using reflected signals. The data was collected in an airplane Cessna flying off the shore of Santa Barbara, California. During flight the direct and sea surface reflected GPS signals were recorded at 20.456MHz.

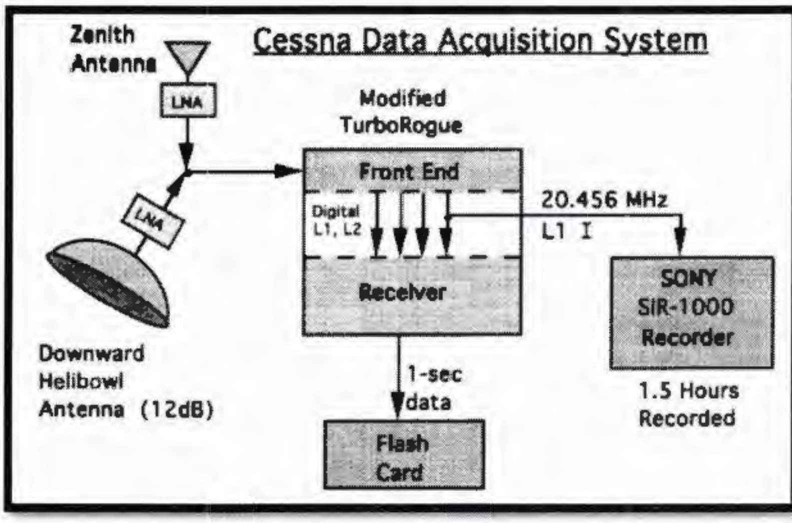


Figure 4-13: Cessna Data Acquisition System

The overall experiment was consisted of a Cessna plane flied over different trains. The placed data acquisition system was initiated for recording reflected GPS signals data. Another approach of TurboRogue was used to drive accurate receiver positioning (22). This experiment helps in finding more precise wave forms, there modeling, the C/A code side lobes exclusions, the atmospheric models and the use of Y-code waveforms to progress results in future.

Taking lead from the concept of reflected GPS signaling and data acquisition, a different experiment was performed for collecting soil moisture data and identifying their train by Scott Gleason in 2006 (23). All previous approaches were performed on near Earth scale and the system was designed for low earth orbits. The low orbit satellite UK-DMC GPS signal were detected by the device of a wide range of surface including the sea ocean, sea ice, and land.

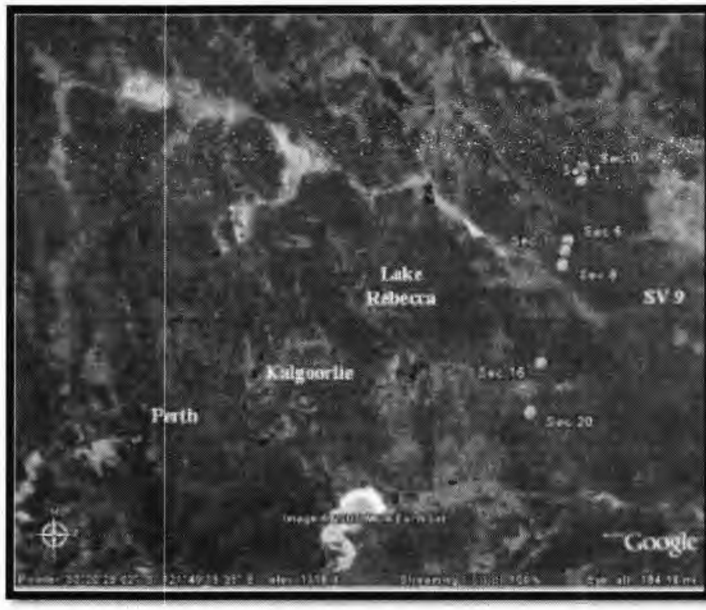


Figure 4-14: Google Earth image of the January 5th 2006 reflection locations

The practical realization of receiving GPS reflected signals remain a challenge due to weak signals and low SNR. For reception of weak GPS reflected signals a custom made LHCP (left hand circularly polarized) high gain antenna was designed with two channels front end data receiving instruments was proposed by M Usman and DW Armitage (24). The incoming reflected signals have very low power levels in comparison to radar altimeter. The aim to overcome this problem was included in the research. The author is hopeful that it can be achieved by correct antenna design, software algorithm and electronic circuit design.

Availability of GPS signals in every weather condition and low cost receiver as compared to other remote sensing devices make this entire practical for researchers. The reflection of the GPS signal rough dielectric surface to produce a number of delayed signals with amplitude proportional to the power reflection coefficient at each point to speculate. The technique became very useful and millions of unexpected results were gathered. The description of the data recorded requires more efforts to perform same experiment at larger scale (23). Similar experiment was performed in Africa, UK and US. The measurements were then calibrated with the information received and if the reflections are responding well the observables can appear such as soil moisture or other surface resources.

The true approach of reflected GPS was used in year 2011 (25) for ocean altimetry. The airborne experiment of sea surface altimetry using reflected global positioning system (GPS) was presented with complete scope. A new method of non-coherent method was adapted. Which can align coherent correlation output of sea surface reflected GPS signals. The relative delay estimation of meter level precision can be obtained in one second and also sea surface height error is expected to be at the same order of magnitude.

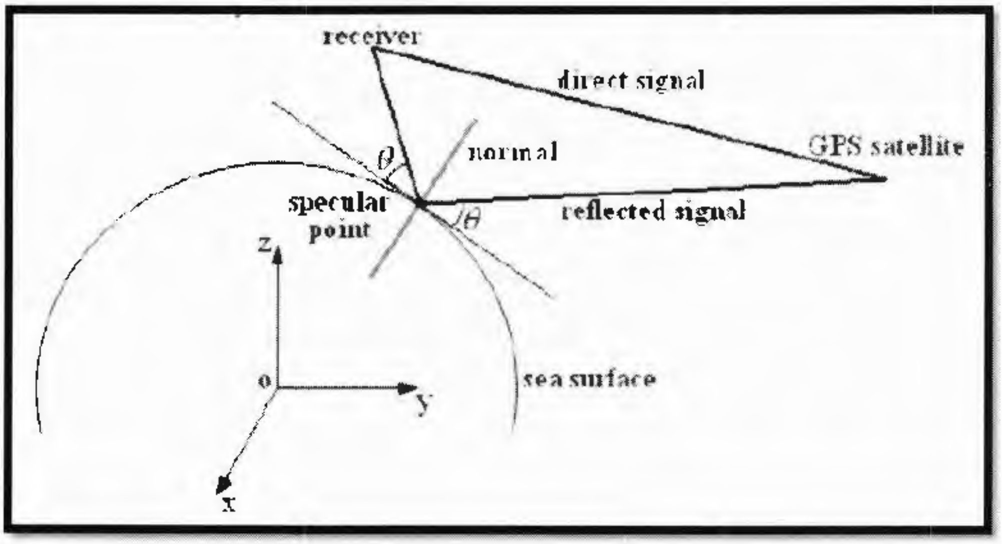


Figure 4-15: Geometry of sea surface altimetry

Number of experiments in series was performed off the coast of Sanya, China, in February and March, 2009. The major objective of experiments was to collect data form aircrafts in order to be able to study reflected GPS signals altimetry and wind speed retrieval. The concept presented in this paper of non-coherent summation is presented for reflected GPS signals (25). The work required for optimizing the intervals of coherent correlations and non-coherent summation, filtering and merging relative delay estimation to improving the precision is still required in future development of the project.

4.3 Review of GPS Remote Sensing Research

A review has been compiled by concluding the research and efforts made for altimetry accuracy and ways to formulate a unique method for altimeter measurement system GPS remote sensing technique. The most relevant research has been carefully selected and reviewed. The data processing can give outcome of: -

1) Over the sea to calculate sea height, speed of wind with direction and prominent wave height.

2) In case of ice it gives ice age duration, thickness and density of the surface.

3) In case of land will gives land moisture, soil contents, biomass, and bistatic imaging.

Efforts have been made to include at least one example from each above-mentioned application.

Katzberg S and L Garrison, NASA Langley Research Center (LARC) has started research in 1996 reflected GPS signals from remote sensing led series describes the theory and mechanisms of this technology. James L. Garrison and co-authors estimated the measurement of wind speed in forward scattered GPS signals (26). The study was based on the paper "effect of sea roughness bistatically scattered signals are encoded with the Global Positioning System", a technique that measures the shape of the cross-correlation signal and a locally generated PRN code presented in (27).

A specific receptor, able to follow the line of sight of the Zenith satellites with right hand circular polarization oriented (RHCP) antenna was used. The camera recorded the cross-correlation function of the reflected GPS signals using an antenna oriented LHCP nadir. The inversion method for bistatic scattering models to estimate wind speed from measurements of the correlation was applied. This allowed the calculation of the surface roughness of the sea so that, in turn, is known to depend on surface wind speed. When searching for the shape of the distribution of signal intensity was compared with analytical models that have used a geometrical optics approach. Two techniques for comparison of these functions were studied. The first recognized that the content of the most important information of the reflected signal is in the slope of the trailing edge of the wave.

The other tried to fit the full form of the waveform by comparing it as a series expansion for the nonlinear least squares estimates. The trial successfully demonstrated the reliable recovery of geophysical data using the shape of the correlation function waveform recorded from the GPS signals forward scattered.

Another interesting aspect of remote sensing with analysis of the surface reflected GPS signals to investigate the circumstances of sea ice (28). The application is particularly useful because the environmental characteristics of these regions. In situ, or the aerial mapping of sea ice conditions caused by the difficulties of traditional instruments only because of inaccessible and hostile environments, the visibility terrible in most of the year and the constant cloud cover. In contrast, the GPS signals are available throughout the day and can be kept for the following signal processing. The system uses the research consisted of two small GPS antennas, edited-in GPS receiver, processor, recorder and cables. Modified by GPS receiver for the correlation between the measured values of output offset of the delay and Doppler showing the lowest level using the LHCP antenna. The main measure was received signal strength is reflected in a series of delays and Doppler values.

Preliminary experiments for observing GPS reflections of Arctic sea ice has shown that a moderate elevation in the air GPS receiver, the size of the reflected signal has been fairly consistent (a strong, narrow waveform of flight) shows that variations in roughness ice was not prominent in the L band. On the other side, the high power was found with significant changes on the runway. This suggests that the peak performance of the GPS signal varies from the reflecting surface and the researchers came to understand that the GPS signal after reflection contains much information other then detecting sea ice (29).

GPS L1 frequency of 1.57542 GHz frequency is optimal for detection of soil moisture at bay. Research conducted by S. Katzberg et al. describes a unique way to calculate soil moisture using bistatic radar (30). The results illustrated that the GPS bistatic radar calculations can detect any smaller change in the reflection of waves with surface. Additional analysis was performed to compare the power of the scattered signal measured in situ samples of soil moisture data from 32 different locations in the field. It was found that the trends of soil moisture from dry to wet levels were measured in a positive way by the GPS bistatic radar measurements. During the theoretical modeling of bistatic surface scattering, it was found that the scale and the breadth of the reflected wave depend on the dielectric permittivity of the soil surface, vegetation surface and surface roughness.

4.4 Concept Effectiveness

The implementation of the subject concept was designed in a way keeping different financial and ground facts in mind. The concept of using reflected GPS signals from air without using any signal transmission to any pointed train or surface was primarily designed for low cost small aircraft flights landing and takeoff in all weather condition with a certain level of accuracy. The design primarily contain two similar receivers on two different positions on the plan i.e. one on the roof of the aircraft for collecting direct data of GPS signals and the other one below the aircraft to record data of reflected GPS signals. These signals strike the surface i.e. ocean surfaces, mountains, moisture surface, etc after emitting from the GPS satellite and returned back in anonymous direction to air after different strikes with different objects or directly strike back to air. Such signals contain enormous number noise in them. The purification of the signals was remained an important desire to retrieved hidden information in recorded data. After the purification of the signals through combination of different filters, the correlation of the signal streams occurred to identify the delays and difference in clock timings as well as information contained in both data sets.

The whole system costs remained at a certain level including the hardware. The effectiveness of the system can be revealed by the fact that un-useful signals in the air contain malicious information from where the identification of the primary altimetry measurements as well as speed of the aircraft can be detected.

5. GPS SPS Signal Acquisition & Hardware

The launch of the Sputnik 1957 was the start of new era in navigation. Through monitoring of the Doppler shift in the radio signals broadcast from the Sputnik satellite. The scientist kept their focus on the determination of tracking and finally used a reversed concept to locate their own position. This idea leads to the deployment of space-based navigation system. Several new satellites were sent into the air to achieve navigation objectives in the history and formulated a complete Global Positioning System (GPS) for standard positioning services (SPS) for whole world and mainly military objectives.

In this thesis, previously we had focused on the how much work has already been done regarding methods and techniques in general, but this portion will exactly focus on the signal processing point of view of GPS signals. To specifically measure the distance of the platform with the help of reflected GPS signals, acquisition of actual GPS data was made and saved in digital format. The hardware consisted of a high gain and directional antenna to capture reflected waves and a circuit that captured the raw data for sampling frequency and precise IF. Complete details of the proposed hardware involved to carry out this experiment is explained in this chapter.

A complete portray of the system has been shown in Figure 5.1.

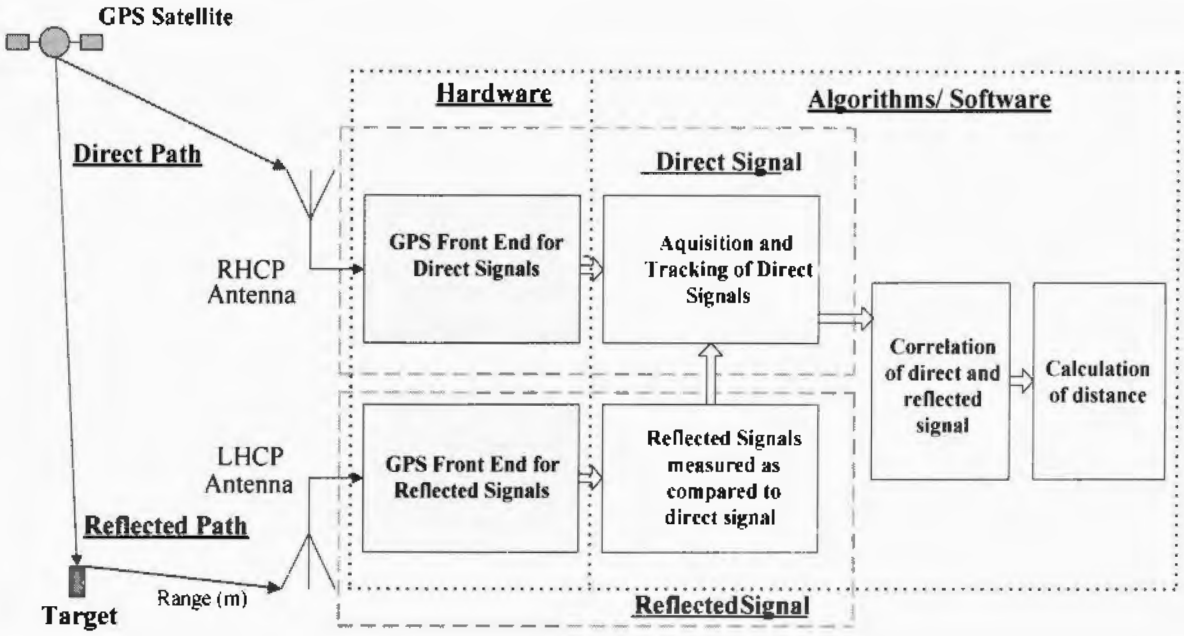


Figure 5-1: Complete Scenario

5.1 System Details

This system consists of four basic constituents, namely, the GPS system, target scenario, the hardware (consisting of high gain antennas with front end data acquisition device) and in the last performs signal processing.

A concept made high gain (Left Hand Circularly Polarized) LHCP GPS antenna receives the reflected signals. The amplitude decreases with every reflection, as the reflection coefficient is less than one and a portion of the signal is absorbed. The polarization of the reflected signal could be changed from (Right Hand Circularly Polarized) RHCP to LHCP depending upon the reflecting material type and angle of incidence (1; 11). The reflected signal might unable to provide required SNRs for correct acquisition. So the direct signal via RHCP will be locked, recorded and proceed for processing. After successful lock, the same oscillator will perform direct and reflected signals processing.

The GPS system and the objective characteristics are explained in the previous chapter. This chapter describes the hardware, which brings together the practical implementation of the system, as well as some of the processes taking place within the GPS receiver.

5.2 GPS Satellite Signal Transmission

The complete GPS system was arranged in 6 orbital planes with four satellites in each, in all 24 active satellites (31). All satellites transmit their time and position in three dimensions. When a receiver is required to get its position, its minimum requirement of signals is from four different satellites. The GPS receiver is a passive device which means they don't transmit any type of signal into air or towards satellite. The receiver always make use of one way Time of Arrival (TOA), which means it measure the transmission time of a wave to reach a receiver from the satellite. The satellite conditions are being monitored from five ground stations strategically placed on the globe i.e. Hawaii, Ascension Island, Diego Garcia, Kwajalein and Colorado Springs. The position and the time data are being updated several times from the network to the satellite every orbit. Only two L band frequencies i.e. L1 (1575.42MHz) & L2 (1227.6 MHz) carries navigation data and acquire gold code from SV using Code Division Multiple Access (CDMA) method. Every SV has its own range of gold codes. The receiver gets time and satellite position from navigation data. One method of using gold codes is to determine the propagation delay by the receiver of the satellite signal. From both frequencies, only L1 frequency is used for the standard positioning services, which is available to all users around the globe. The accuracy of the frequency is limited to 100m horizontally and 156m vertically on the plane. Another precise positioning service (PPS) is only available to US government and their military users due to its security enhancement by using two encrypting services i.e. Anti-spoofing (AS) and Selective Availability (SA). These restrictions were implemented in 1995 after the full gain of the PPS services and to block them publically.

5.3 The GPS Receiver

At the heart of imaging equipment is a front-end of the GPS receiver. It makes sense to start a hardware description and a summary of the GPS receiver. The GPS receiver is a traditional CDMA signal processing algorithms. A typical RF front-end in the GPS receiver includes an antenna, amplifiers, local oscillator, mixers and analog-digital (ADC). The GPS signal was down converted, amplified and digitized for processing and sampling. The processing of base band signals was made to get receiver position by using software routines, as shown in figure (5.2). Like all CDMA systems, the design of a GPS receiver has some major challenges. The satellites travel almost 7,000 km / h (3,874 m / s), causing a Doppler effect from -5000 to 5000

Hz The satellites are about 20200 km away, and the transmission power is very low, typically only 50W (1; 11).

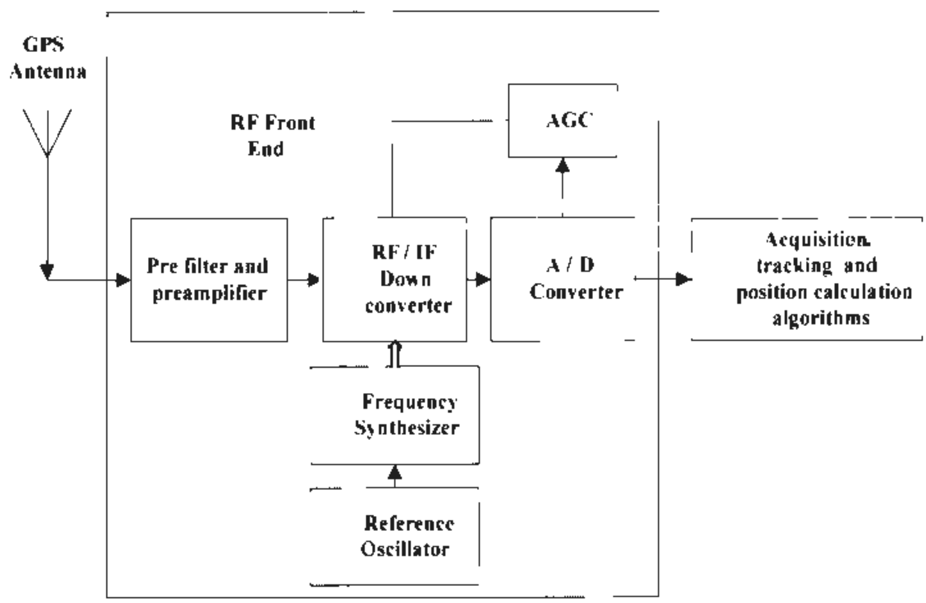


Figure 5-2: A simplified GPS receiver

As shown in Figure (5.2), is the first part of the receiver and the GPS antenna is designed specifically for the GPS. The most common and commercially used antenna is a low-profile micro strip patch antenna. The antenna is designed to acquire GPS Live is usually right hand circular polarization (RHCP) versus input signal. The main objective of the signal conditioning block (pre-filter and pre-amplifier) is to remove interference signal components. However, the purpose of the block down-conversion is to convert the received signal from RF to 1575.42 MHz for a more manageable intermediate frequency (IF) of a few MHz. The down-conversion is carried out by a mixer, mixing the input signal with a local oscillator (LO) signal. The LO must be very stable and accurate so that the new IF is well defined. ADC (Analogue to Digital Convertor) is responsible for sampling down converted analog signal to digital format suitable for signal processing (1; 11). The number of bits used to represent the digital signal when the commercial GPS receivers are often set to 1 or 2 bits. The small number of bits simplifies the computations in the GPS receiver during later signal analysis.

5.4 GPS Signal Acquisition

As compared to standard radar altimeter the reflected GPS signals have very low power levels. Part of the research effort was to solve this crucial problem. This was achieved by careful design of the antenna, suitable electronic circuits and algorithms for acquisition. The purpose of all these efforts was:

a) Find satellites signals visible to the receiver

b) Estimate coarse value of the C/A code phase

c) Estimate coarse value of the carrier frequency

d) Capturing of the weak reflected signals

e) Estimate the propagation delay of the signals

f) Refine carrier search results and correlate them to find required measurements

When the satellite moves directly towards or away from the receiver, it approximately produces maximum of ~5kKz Doppler shift. The Doppler value and sign depend on the angle between signal line of sight vector and satellite's motion vector. The receiver motion also creates a Doppler offset of 1.46Hz per each 1km/h because of the Doppler value and sign depend on the angle between signal line of sight vector and this time receiver motion vector, therefore we initially place our receiver at a fixed point.

The whole frequency search band is divided into frequency bins. The size of the frequency bins depends upon the desired integration time and the desired maximum SNR loss due to frequency mismatch. A common used Doppler frequency bin size for acquisition of L1 signal is 500Hz. This division will provide a total of 41 different frequencies of a band of 20 kHz. The minimum of one spreading code sequence is used otherwise the PRN properties will be degraded by min 1ms for GPS. The total signal length should be m * code length, where m >0. When m >1, the SNR will be improved and the data bit transitions can destroy integration results. This may result in occupation of more time for signal acquisition due to longer time in signal processing and reduced frequency bins will require checking more frequency bins.

After the signal has been converted to IF frequency the code offset and carrier Doppler shift are calculated. A high level diagram depicted the major operations on GPS data after output from GPS front end is shown in Figure (5.4) (1; 10).

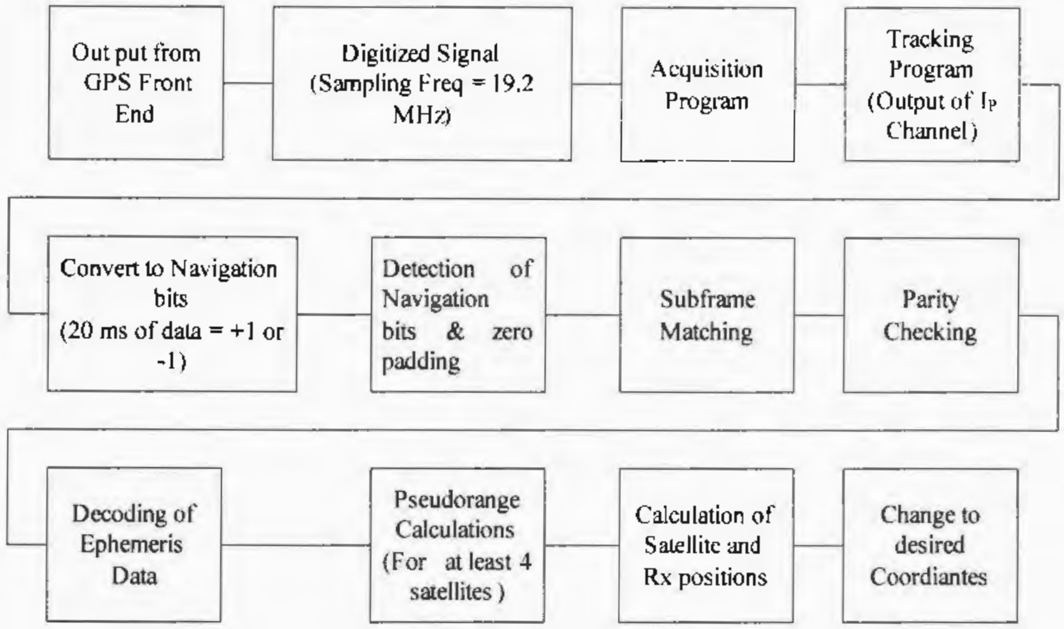


Figure 5-3: Block diagram of acquisition, tracking and position calculations

The purpose of the acquisition process is to identify whether a particular satellite is visible or not.

There are several techniques used for the acquisition of the GPS SPS signals worldwide. These techniques are:

5.4.1 Serial Search Acquisition

One of the most common methods used for the acquisition of GPS SPS signals is serial search acquisition method. It is a straight forward method of acquisition of search of all possible combinations (bins) of code phase and carrier frequency.

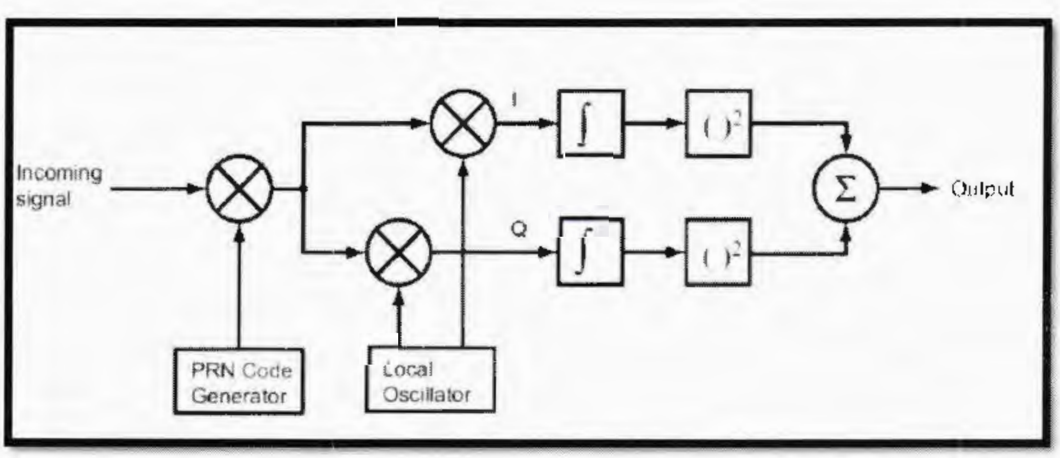


Figure 5-4: Serial Search Acquisition

The total number of the combinations to search will be 41 different carrier frequencies having 2046 different C/A code phases. The total output of the system can be derived from a very simple shown in equation 5.1 below.

$$\underbrace{1023}_{CodePhase}\underbrace{\left(2\left(\frac{10000}{5000}\right)+1\right)}_{Frequencies} = 1023 \times 41 = 41943\,combination$$ **Equation 5-1**

The calculation of each code is very simple therefore the implementation in the hardware remains an easy part of the implementation. It also shows many drawbacks due to high number of combinations and makes this method very slow, especially for high sensitivity signal acquisition for multiple signal correlators to increase acquisition speed.

5.4.2 Parallel Frequency Space Search Acquisition

In this method to find a parameter is performed in parallel and a Fourier transform is applied to transform the time domain to frequency domain. The acquisition of parallel frequency search in space and that gradually increases over 1023 different code phases (22). The transformation frequency domain has been difficult in terms of hardware implementation. A detailed diagram has been shown in the Figure 5.6.

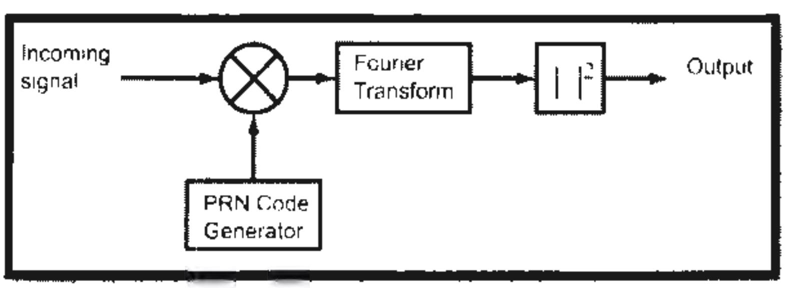


Figure 5-5: Parallel frequency space search acquisition

5.4.3 Parallel Code Space Search Acquisition

The goal of the acquisition process is to perform a correlation with the incoming signal and a PRN code. Instead of multiplying the input signal with a PRN code with 1023 different code phases as done in the serial search acquisition method, it is more convenient to make a circular correlation between the input and the PRN code without shifted code phase. In the following

The combination of equation (5.2) and (5.3) gives the DFT of the cross-correlation between x and y:

Equation 5-9

$$Z(k) = \sum_{n=0}^{N-1} \sum_{m=0}^{N-1} x(m)y(n+m)e^{-j2\pi kn/N}$$

Equation 5-10

$$= \sum_{m=0}^{N-1} x(m)e^{-j2\pi kn/N} \sum_{n=0}^{N-1} y(n+m)e^{-j2\pi k(n+m}$$

Equation 5-11

$$= X^*(k)Y(k)$$

We can conclude that the connection between a time-domain correlation and the frequency domain representation is almost similar to the association between convolution and its frequency domain representation. The only difference being the Fourier transform of one of the two input sequences should be complex conjugated prior to multiplication. When the frequency domain representation of the correlation is found, the time-domain representation can be found through inverse Fourier transform.

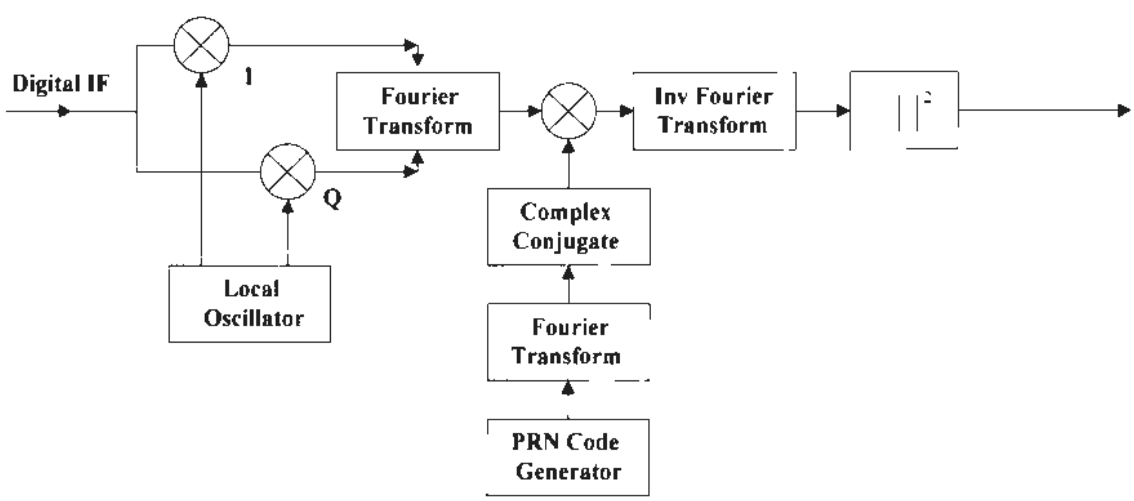


Figure 5-6: Block diagram of the parallel code phase search algorithm

Figure (5.7), describes the block diagram of a parallel code phase of the algorithm. The signal must be multiplied by a locally generated carrier signal. Multiplying the carrier signal to produce signals, and multiplying by 90 ° phase was transferred to version creates a signal carrier signal Q. Both I and Q signals to form a complex signal x (n) = I (n) + JQ (n) using the DFT. The generated PRN code is transformed into the frequency domain, and the result is the complex conjugate. Now the Fourier transform of the signal is multiplied by the complex conjugate of Fourier locally produced PRN code. Result of propagating changes with the time domain by inverse Fourier transform. Absolute value of the output of inverse Fourier transform is the correlation between income and the PRN code.

If a peak is present in this context, the index of this peak marks the PRN code phase of the input signal. The Previous methods of acquisition, the parallel code phase search acquisition method to reduce the search space for 41 different carrier frequencies. PRN code phase is more accurate than other methods because it gives a correlation value for each phase of the sample code. A Matlab ® code is developed that can make the GPS signal acquisition based on this method, and detail the chapter on the simulation.

5.5 Design, Characterization and Testing of LHCP Antenna

As shown in Figure (5.1), a high-gain custom LHCP helical antenna is used for reception of GPS signals reflected. It is understood that the GPS signals at transmission are right hand circular polarization (RHCP). Upon reflection of an object, the signal polarization can be reversed and become LHCP (32). The polarization of an electromagnetic wave is defined as the orientation of the electric field vector. Then, the circular polarization is such that the tip of the electric field vector describes a helix and can be called "right" or "left", depending on whether the propeller has the thread of the right hand or left hand screw, respectively viewed from the direction of wave propagation (32).

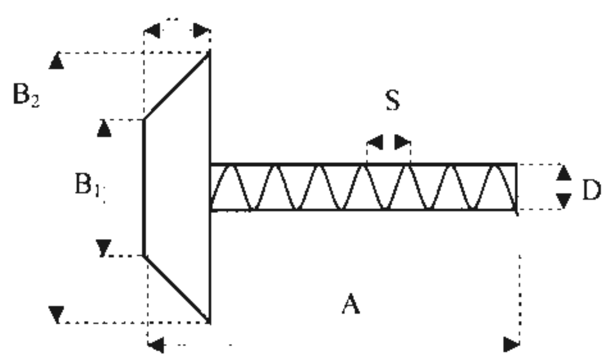
The strength of the reflected signal depends on surface roughness and dielectric properties of an object that reflects the number of reflections. After the inverse square of the signal is reflected in running the ball with a radius of 10 cm would be the absorption rate (dB) 20 log10 (R/0.1), where R is the field by a "spotlight" you can find a place. For example, this range of attenuation is 25 meters approximately 48 dB. The first generation of experiment was conducted on relatively short range to ensure the concept and simple to set.

Antenna gain and ignoring the signal would be about 48 dB below the direct signal received by an antenna pointing to zenith RHCP GPS. GPS signals directly to a ms acquisition time is sufficient for signal detection in the case of a strong signal. Instead, the reflected signal is related by a long period of time to extract weak signals and to cancel uncorrelated noise. A processing gain of about 25 to 30 dB compared with the direct signal is possible if the reflected signal is integrated over 250 to 500 ms. Another 20 dBi antenna gain pure was obtained with the help of a custom LHCP helical antenna.

The measurements made by a GPS antenna LHCP has been documented in (32) & (33). But the detailed design and properties of such an antenna is generally not available in the open literature. Many discuss the research efforts LHCP antenna as a building block in their pictures or submit it as an off-the-shelf. It was decided to assemble a custom-made high-gain LHCP helical antenna for receiving reflected GPS signals. Using this antenna reflected GPS signal acquisition was possible, which was one of the biggest challenges during the research. The design and testing of the antenna has been documented in (24).

Diagram of the antenna is shown in Figure (5.14). As mentioned in (34) the optimum size of the cone will be when B2 = 2.5λ, B1 = H = 0.75λ and 0.5λ (where λ is equal to a wavelength equal to 0.19 and GPS M).

Figure 5-7: Helical antenna with truncated cone shaped base plate



5.5.1 Description of the electronic circuit

The design requirement for the data collection unit of the imaging system was a low noise, dual-input GPS receiver which operates at the frequency used by the GPS satellite signal. Initial design reviews led to the adoption of two circuits MAX2741 as a basis for design. An integrated 2 or 3-bit analog to digital converter (ADC) (1-bit characters, 1 or 2-bit MAG selectable) samples the second IF and outputs the digitized signals. The MAX2741 GPS front offers a high performance super heterodyne receiver with the advantage of using existing system clock references. The two receivers and its peripheral components are housed in boxes with independent testing multipoint connection to the land of the PCB. The MAX2741 accepts the configuration information in a CPLD SPI interfaces Xilinx. The last device acts as a signal to connect the entire design, which allows flexible interconnection of various design elements.

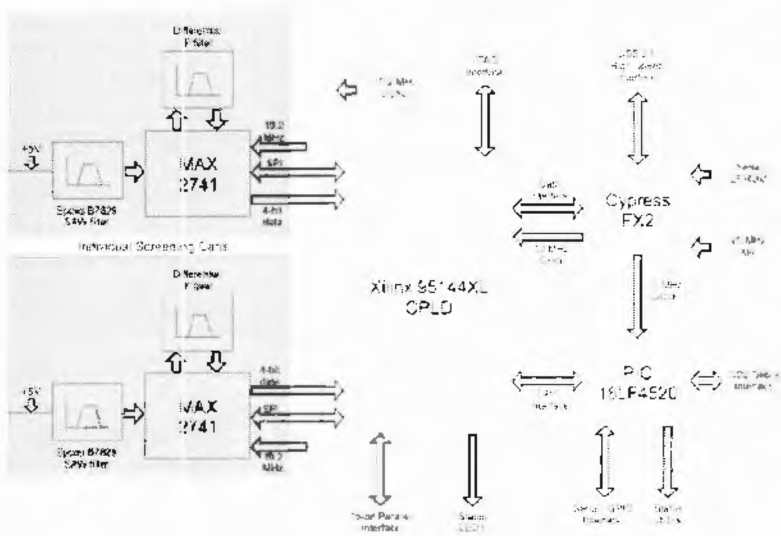


Figure 5-8: Block diagram of the system hardware

Data has been captured using a National Instruments PCI-6534 DAQ board, connected to the parallel port of the CPLD, which acts as system interface to the PC. The GPS IF signal is stored in the HDD as eight bit data with the first 4 bits representing the direct signal and last 4 bits representing the reflected signal or vice versa. This data file is accessed during image signal analysis.

A four-layer PCB (1.6 mm thick FR4) has been used. One of the internal layers is a ground plan. The assembled PCB is shown in figure (5.16). One front end (channel A) receives the direct signals from the satellites while the other (channel B) receives the reflected signals.

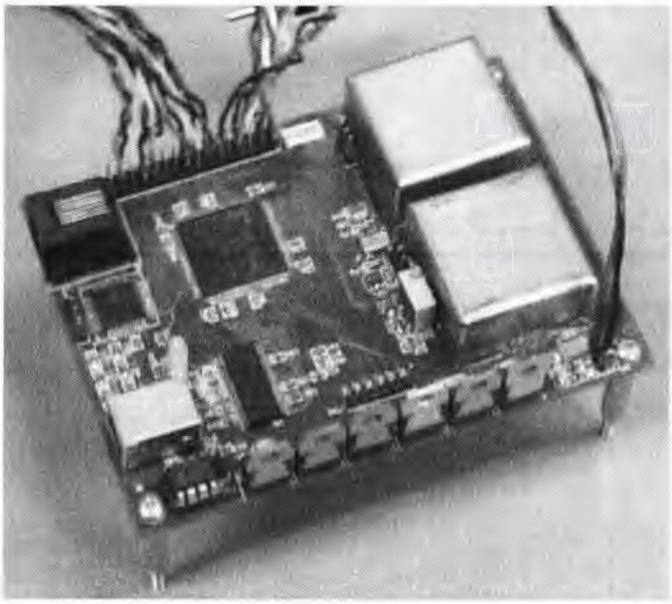


Figure 5-9: Two-channel GPS front end and data capturing device

5.5.2 Acquisition of Direct and Reflected GPS Signals

In order to acquire real data from GPS with the help of a data capture device and confirm that the signal received by the antenna is actually reflected LHCP signal, the direct signal was acquired by the off-the-shelf Bullet RHCP Trimble III GPS antenna. The experiment was carried out against a large brick building. The RHCP antenna was directed towards the satellite, while the LHCP antenna was in position to receive the signal bouncing off the building at a distance of about 25m.

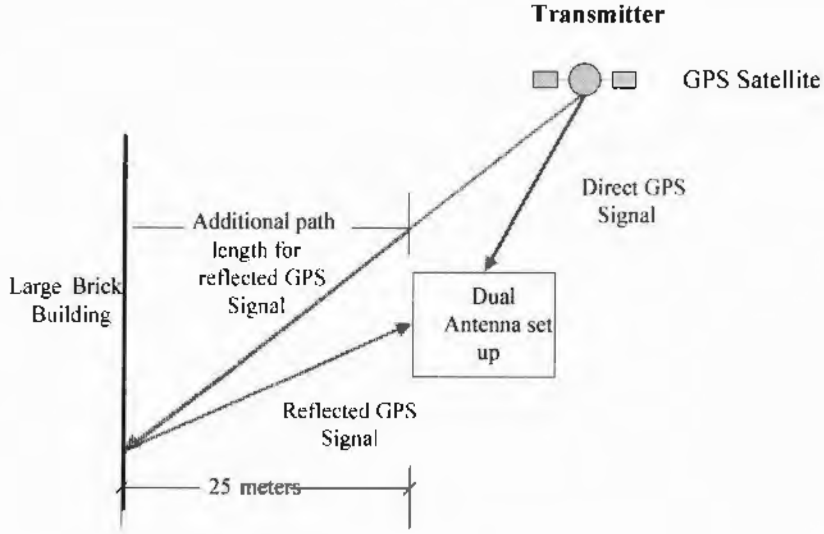


Figure 5-10: Set up for detection of reflected GPS signals

The LHCP antenna geometry with reference to the visible GPS satellites played a key role in signal reception. The satellite most appropriate (in terms of signal strength and visibility) is BIIRM GPS-3 (PRN 12) and was chosen as the reference satellite. Angles of elevation and azimuth of the satellite were calculated using a commercial GPS receiver. The antenna was placed either to receive the satellite signals reflected from the reference wall as in Figure (5.9).

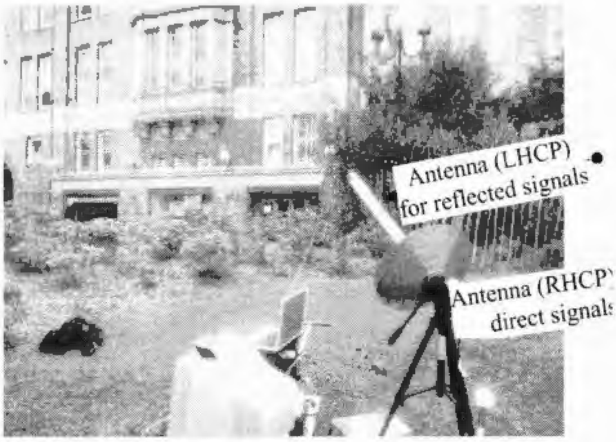
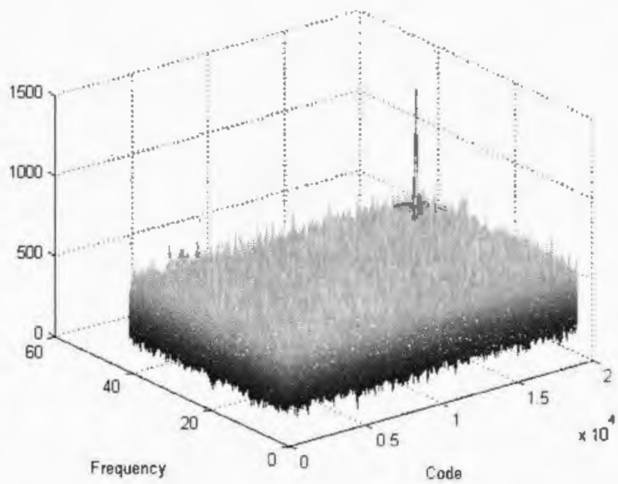
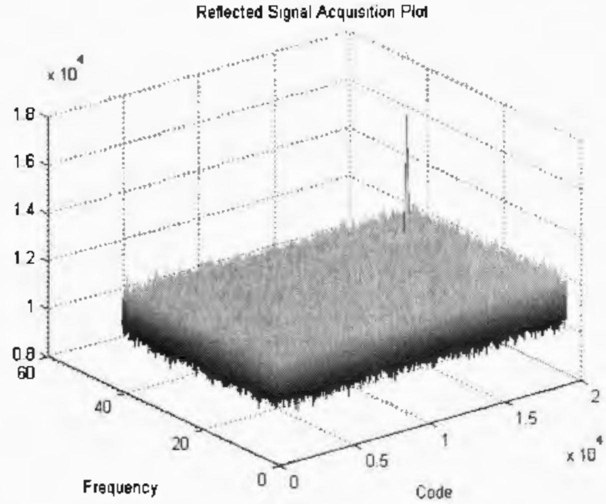


Figure 5-11: Arrangement for the antenna

As expected a very strong signal was received with RHCP GPS antenna that allows the acquisition of the signal is good, even for a few ms integration time as shown in Figure (5.10(a)). The relatively weak signals were acquired by the antenna reflects LHCP integration time required much longer (200 ms) to achieve comparable SNR. As shown in Figure (5.10) the frequency two signals are the same, but the code is slightly different, corresponding to the extra distance that the reflected signals have to travel and can attest to the Figure (5.10(b)) where the correlation peaks of the two signals has been extended to facilitate analysis.



(a)



(b)

Figure 5-12: Comparison of acquisition plot (a) (acquisition time of 4 ms) for RHCP antenna (b) (acquisition time of 200 ms) for LHCP antenna

The hardware organization has been made in a way to gather direct and reflected GPS signals as shown in Figure (5.9). We know that to perform calculations, the direct signal will be acquired by the GPS receiver, correlating the received code locally generated C / A code and the variable delay and Doppler until the correlator output is maximized. The distance of the GPS satellites as well as onset received time will play a vital role in the calculation made by appropriate algorithms.

The length of a single C / A code is 1023 chips and is transmitted at a frequency of 1,023 MHz (35). Taking into account the speed of light, the length of a chip is 300 m. The GPS signal is sampled at a rate of 19.2 MHz. So, each sample corresponding is about 15 meters (3 x 108 / 19.2 x 106). To distinguish between direct and reflected GPS signals, we require a path length between the direct and the reflected signal of 15 meters or more. For example, if the sample correlation between the high-precision signal is detected and reflected signal 12 751 12 753, which shows the difference between the two code examples, and is regional manager for a distance of about 30m. During the experiment carried out in samples of the difference directly to the code and reflects the signal was 3 or 4, which seemed to be about 45-60 meters, and is responsible for the distance round trips between the antenna and a large building brick or a reflective surface. Figure (5.11(a)) compares the peak of the direct and reflected signal correlation clearly demonstrates the path difference. The scale for the value of consistency (Y axis) is different for the two signals due to the different acquisition times.

(a) **(b)**

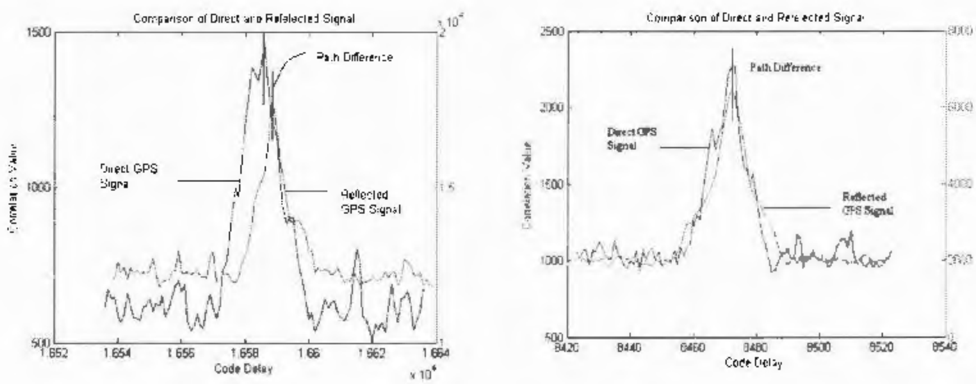


Figure 5-13: Comparison of direct and reflected GPS signals for (a) 50 m (b) 4 m (round trip distances)

To verify the results, GPS, the data were collected at a position just two meters from the building or reflective surface. A path difference of one code examples have been observed in the direct and reflected signal, as shown in Figure (5.11(b)). A mirror reflects almost the GPS signal was received indicating an optimum geometry for the reception of weak reflected signals. It is clear that putting in place the antenna close to the wall of the sample code the difference between direct and reflected GPS signals is reduced.

Thus, the experimental results showed that the signal at the antenna is actually the LHCP reflected signal and construction of equipment was a successful and shown in Figure 5.12.

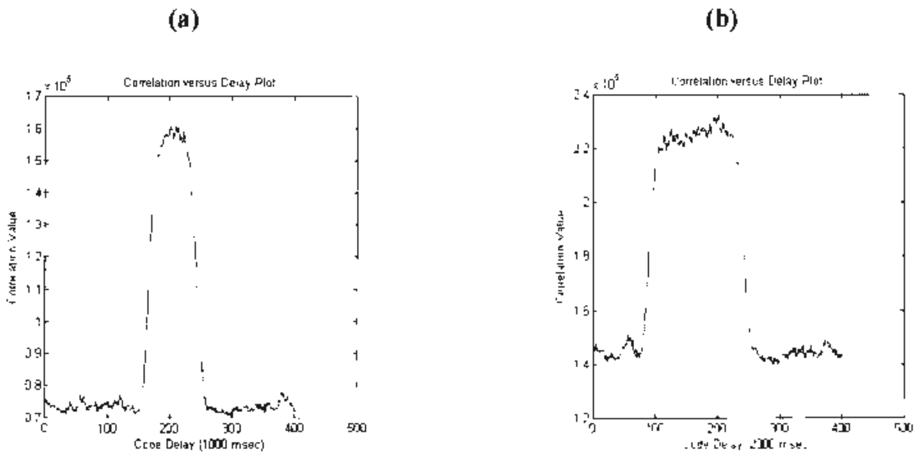


Figure 5-14: Comparison of acquisition plot for acquisition time of (a) 1000 and (b) 2000 ms

This procedure can be used to measure the height of the airborne radar platform, in a passive manner. If the sampling rate is further increased the measurement accuracy can be improved with some small improvements, the system can be used to establish the basic, inexpensive, and covert / passive (moving target indicator) radar. Following are few advantages of GPS based altimetry the system.

GPS altimetry has the attraction that user can take advantage of the expensive GPS infrastructure maintained for navigation purposes and no dedicated transmitter is required.

There are more simultaneous measuring opportunities, one for each GPS satellite in view. The GPS satellite with optimum geometry in terms of signal strength and visibility can be selected to receive the direct and reflected GPS signal. It is also possible to improve the signal power resolution by acquiring data from two separate GPS satellites having different orbiting geometries and overlapping the results.

One of the main advantages of the system is the cost effectiveness. The hardware, comparable in size and complexity to a notebook computer, can be built for a fraction of the cost of traditional radars, space-borne equipment and other sensors.

Another important benefit is that the operation will be covert (no signal will be transmitted as compared to ordinary radar) and not susceptible to enemy jamming activities. The GPS operates round the clock and its signals cover the entire earth surface. At least five GPS satellites are usually visible from an unobstructed location.

6. Simulation & Experiments

This chapter furnishes a detailed account of the computer code generated in Matlab ® 8.0 software, which was developed to acquire and compare the direct and reflected GPS signals. The whole concept of this thesis was based on the potential acquisition of reflected signals as well as its correlation with direct signal. The processes simulated included the satellite orbits and coordinate system, code generation, GPS signal acquisition and plotting. The behavior and results of the GPS calculation was recorded with maximum level of precision. The coherent acquisition was carried out on GPS data ; however the length of the data was reduced to smaller chunks to facilitate signal processing. .

6.1 Detailed Code Description

In order to further understand the Matlab ® code, a more detailed code execution sequence diagram showing the code and its constituent functions is given in Figure 6-1. As depicted in the figure the program starts with specifying the initial values for setting up sample frequency over time to perform signal acquisition.

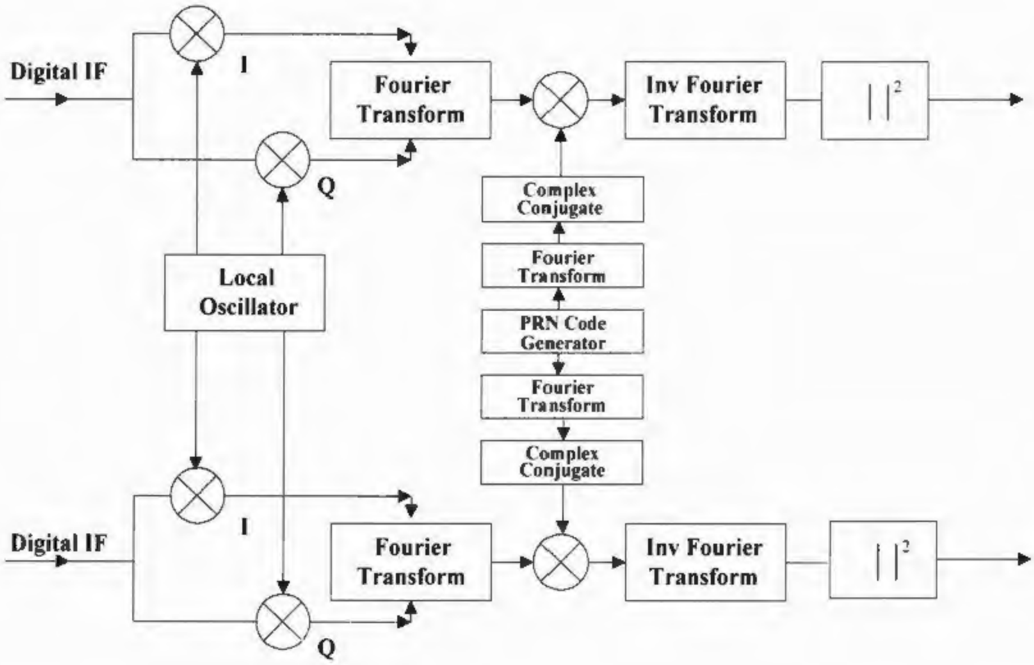


Figure 6-1: Detailed Code Execution Sequence

It was necessary to acquire both direct and reflected signals by tracking GPS satellites using custom antenna and hardware as mentioned in earlier chapters. The initial sampling frequency was set in the program to be 19.2 MHz. Different frequencies have different impact on the data acquisition process.

S/N	Variable	Description
1	SampleFreq_nom	It specifies the size of the sample utilized for the further calculations.
2	ts and ts_r	It specifies the sampling time for a single instance to handle in one msec.
3	acq_threshold	Determines the threshold of the signal detector

The signal was received with the help of antennas designed for reception of directed and reflected GPS signals. It is imperative to perform acquisition on the data hy dividing it into chunks of manageable size. It will help in avoiding OUT OF MEMORY message. The selection of number of chunks remains an important aspect for running numerous calculations on it. A 10 m sec part of the first segment was selected to be opened at one time shown in Figure 6-2.

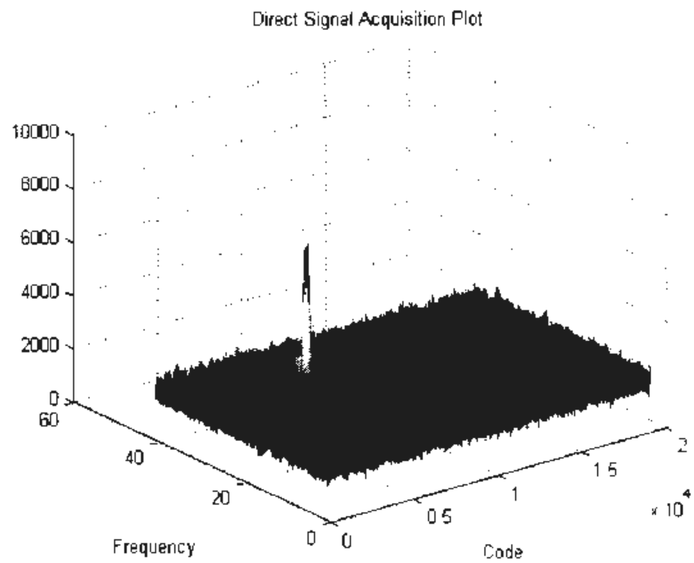


Figure 6-2: Direct Signal Acquisition Plot

The spike shown in the figure is the actual correct/ strong signal for processing. Most of the noise or unwanted signals were spread across the spectrum as blue surface. The gathered data was then engaged in loop for analyses of the segments and multiplication with the signal generated by oscillator. This multiplication results are then processed by using Fourier transformation. The Fourier transform is a mathematical operation with many applications in physics and engineering that expresses a mathematical function of time as a function of frequency.

On the other hand, a pseudo random code generator is used for the generation of a sequence of code and then performs Fourier transformation on it subsequently. The results were in parallel further processed and multiplication was performed after taking complex conjugate. Both results were further multiplied to perform Inverse Fourier transformation for final output shown in Figure 6-4 and Figure 6-5 respectively.

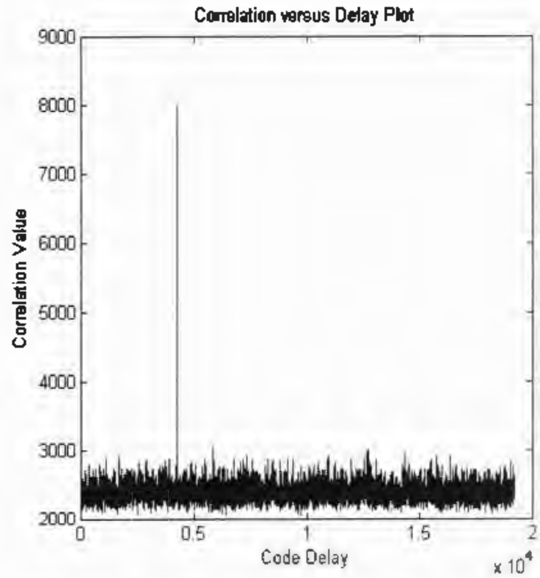


Figure 6-3: Correlation verses Delay Plot (a)

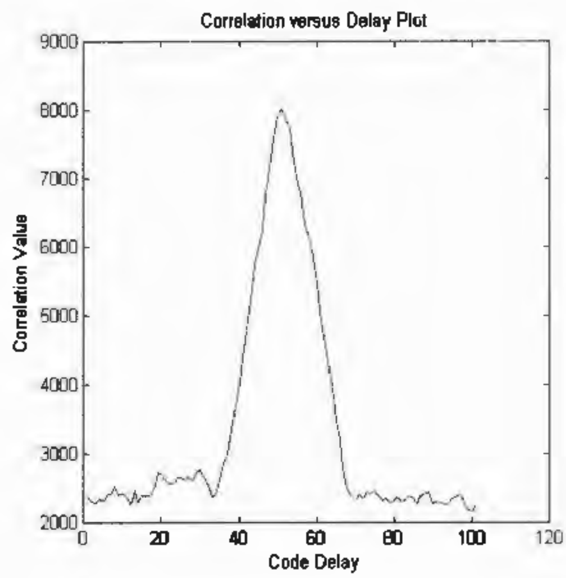


Figure 6-4: Correlation verses Delay Plot (b)

A similar process of signal processing was performed on adjacent channel for reflected GPS signals.

6.2 Functions Description

The functions used for the execution of all code are defined in the table 6-2 below.

S/N	Variable	Description
1	f	Center frequency without Doppler

2	goldsample1	It specifies the generation of pseudo random numbers
3	Prn .	It load the gold codes i.e. prn for GPS
4.	template_f.	It stores PRN of satellite vehicles
5	S	It stores number of segments or chunks
6	Fid	Opens the stored data files
7	Fseek.	It points to the requisite place in the file.
8	Signal	It carries the direct and reflected signals for processing
9	For	It specifies the execution of code in loops by performing Fourier transformation and its inverse on the request function code.
10	Results	Specifies the storage of results for generation of figures.

Table 6-1: Functions Description

6.3 Code Generation

SV PRN Number	C/A Code Tap Selection	C/A Code Delay Chips	First 10 C/A Chips
1	$2 \oplus 6$	5	1100100000
2	$3 \oplus 7$	6	1110010000
3	$4 \oplus 8$	7	1111001000
4	$5 \oplus 9$	8	1111100100
5	$1 \oplus 9$	17	1001011011
6	$2 \oplus 10$	18	1100101101
7	$1 \oplus 8$	139	1001011001
8	$2 \oplus 9$	140	1100101100
9	$3 \oplus 10$	141	1110010110
10	$2 \oplus 3$	251	1101000100
11	$3 \oplus 4$	252	1110100010
12	$5 \oplus 6$	254	1111101000

13	6 ⊕ 7	255	1111110100
14	7 ⊕ 8	256	1111111010
15	8 ⊕ 9	257	1111111101
16	9 ⊕ 10	258	1111111110
17	1 ⊕ 4	469	1001101110
18	2 ⊕ 5	470	1100110111
19	2 ⊕ 6	471	1110011011
20	4 ⊕ 7	472	1111001101
21	5 ⊕ 8	473	1111110011
22	6 ⊕ 9	474	1111110011
23	1 ⊕ 3	509	1000110110
24	4 ⊕ 6	512	1111000011
25	5 ⊕ 7	513	1111100011
26	6 ⊕ 8	514	1111110001
27	7 ⊕ 9	515	1111111000
28	8 ⊕ 10	516	1111111100
29	1 ⊕ 6	859	1001010111
30	2 ⊕ 7	860	1100101011
31	3 ⊕ 8	861	1110010101
32	4 ⊕ 9	862	1111001010
33	5 ⊕ 10	863	1111100101
34	4 ⊕ 10	950	1111001011
35	1 ⊕ 7	947	1001011100
36	2 ⊕ 8	948	1100101110
37	4 ⊕ 10	950	1111001011

Table 6-2: Code-phase assignments and initial code sequences for C/A code

Fundamental PRN sequences are generated and assigned to the individual SV with separate codes for each satellite. As explained, there are two 10 bit shift registers involved in the generation of C/A code that generate the PRN sequences with length $2^{10} - 1 = 1{,}023$ bits. The first shift register, G1 has feedback taps connected to stage 3 and 10 and fed back to stage 1.

The G2 sequence is formed by delaying the G2 sequence by an integer number of chips ranging from 5 and 950. Each C/A code PRN number is associated with two tap positions on G2. Table (6-1) describes these tap combinations for all defined GPS PRN numbers and also specifies the equivalent delay in C/A code chips. The first 32 PRN numbers are reserved for the space segment. Five additional PRN numbers, 33 to 37, are reserved for other users such as ground transmitters. The C/A codes 34 and 37 are identical.

Using Matlab® programming the individual PRN codes is generated and a different PRN code is assigned to each SV. These are bi-phase codes consisting of sequences of −1 and +1.

6.4 Acquisition Function

As mentioned in chapter 5 the acquisition function utilizes the parallel code phase search acquisition method. A detailed account of this method was furnished in section (5.4.3). We know that the received signal s is a combination of signals from all n visible satellites: -

$$s(t) = s_1(t) + s_2(t) + \cdots + s_n(t) \qquad \textbf{Equation 6-1}$$

When acquiring a satellite k, the incoming signal s is multiplied with the local generated C/A code corresponding to the satellite k. To identify whether or not a satellite is visible, it is sufficient to search the frequency in steps of 500Hz (36).

6.5 Acquisition of Direct and Reflected GPS Signal

As compared to ordinary radar altimeter the incoming reflected GPS signals have very low power levels, it is imperative to detect this weak signal and compare it with direct signal and find the distance of the receiver. The direct signal is used to obtain a lock on the GPS signal and find the Doppler frequency. As part of the research endeavor the aim was to overcome this core problem. This was achieved by careful antenna design, suitable electronic circuit and acquisition algorithms. The set up for acquisition of direct and reflected signals was mentioned in section 5.5.2 of last chapter.

As mentioned earlier the length of one C/A code is 1023 code chips and is transmitted with a frequency of 1.023 MHz. Taking into account the speed of light the length of one chip is 300 m. As mentioned earlier the signal is sampled at 19.2 MHz. Thus each code sample corresponds to about 15 meters (3 x 108 / 19.2 x 106). It is possible to distinguish between the direct and reflected signal if the path length between direct and reflected signal is at least 15 meters or more. For example, if the correlation peak in sample precision for direct signal is detected at 12751 and for reflected signal at 12753, it demonstrate a two code sample difference and corresponds to a spatial distance of about 30m. During the experiment performed the difference in code samples of direct and reflected signal was 3 or 4 which came out to be about 45 to 60 meters and corresponds to the round trip distance between antenna and the large brick building or reflective surface. Figure (6.5a) compares the direct and reflected signal correlation peaks clearly depicting this path difference. The scale for the correlation value (y-axis) is different for both signals on account of the varying acquisition time.

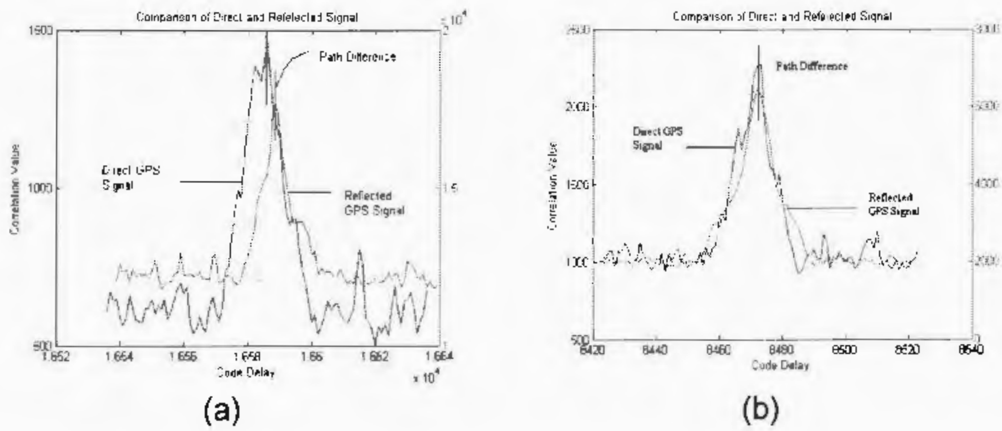


Figure 6-5: Comparison of direct and reflected GPS signals for (a) 50 m (b) 4 m (round trip distances)

In order to verify the results, GPS IF data was collected at a position of only two meters away from the building or reflecting surface. A path difference of only one code samples was observed among the direct and reflected signal as shown in figure (6-5b). A near specular GPS reflected signal was received suggesting an optimum geometry for reception of weak reflected signals. It is evident that by bringing the antenna set up closer to the brick wall the code sample difference between direct and reflected GPS signals is decreased.

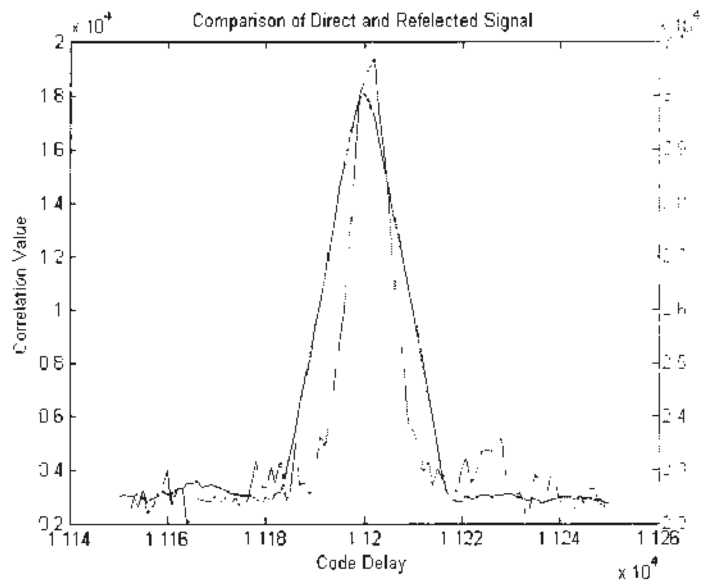


Figure 6-6: Final Result after Comparison

Thus the experimental results shown in Figure 6-7 substantiated that the signal present at the LHCP antenna is in fact the reflected signal and construction of the hardware has been successful and is ready for installation in small airplane or UAV where further data can be acquired and the height of the aerial platform can be computed with the help of the designed hardware and software developed for this purpose.

6.6 Conclusions

The experiments and the results concluded that the GPS reflected signals can be used for calculation of distance by correlation with direct signals. It is a passive and cost effect way to perform distance calculations or ranging. The experiments were performed in front of large building, however, results have validated that if the hardware is installed on an airborne platform and more data is acquired, the same concept may be used for further experiments. The same code can be used to calculate the distance of the moving platform above the surface of earth. The thesis provides the basis to prepare a cost effective GPS reflected signal based Radar Altimeter.

6.7 Future Work & Recommendations

The purpose of this thesis is to identify potential applications of reflected GPS signals. However, it is pertinent to mention that further experiments can be carried out the next phase of the project will be to gather more data. It is imperative that a good peak of reflected signal is present for carrying out correlation with direct signals.

More work should be carried out on antenna design to increase the gain and capacity of capturing reflected signals. The enhancement in the gain of the antenna will equally help in provision of higher correlation peaks.

7. Bibliography

1. **Hegarty, Elliott Kaplan & Christopher.** *Understanding GPS: Principles and Applications, Second Edition.* s.l. : NavTech GPS, April 2008.
2. **Xu, Guochang.** *GPS theory Algorithms and Applications.* s.l. : 2nd edition Springer, June 2007.
3. **Tsui, James Bao-Yen.** *Fundamentals of Global Positioning System Receivers – A Software Approach 2nd Edition .* s.l. : A John Wiley & Sons, Inc. Publication, 2005.
4. **Kaplan, E.D.** *Understanding GPS Principles and application.* s.l. : Artech House Publishers.
5. **Kaplan, E D.** *Understanding GPS Principles and Application.* s.l. : Artech House Publishers, Nov 2005.
6. *3D Multistatic SAR System for Terrain Imaging based on Indirect GPS Signals.* **Bijan Mojarrabi & Yonghong Li, C.R., Eugene Donskoi, John Homer.** 2002, Journal of Global Positioning System, pp. Vol. 1(No. 1): p. 34-39.
7. **Hoel), Christian Wolff (Revised by Karina.** http://www.radartutorial.eu/01.basics/rb04.en.html#this. *http://www.radartutorial.eu/01.basics/rb04.en.html#this.* [Online]
8. *http://www.wisegeek.com/what-is-an-altimeter.htm.* [Online]
9. *Direct Path Interference Suppression in Bistatic System: DTV Based Radar. .* **Rajesh Saini, M.C., V. Lenive.** s.l. : Proceedings of the International, 2003. p. Radar Conference.
10. *A Radio Altimeter for Landing UAVs or Small Aircraft.* **Vidmar's, Matjaž.** Dec 2010.
11. *Coherence time and statistical properties of the GPS signal scattered off the ocean surface and their impact on the accuracy of remote sensing of sea surface topography and winds.* **Cinzia Zuffada & Valery, Zavorotny.**
12. **Strawhorn, Harold.** *COMPARISON OF F-M AND PULSED-TYPE RADIO ALTIMETERS.* U. S. Naval Postgraduate School : Annapolis, Maryland, 1949.
13. *DE- convolution of Images obtained by Co-relation of direct and reflected GPS signals.* **Dr. M Usman & D W Armitage.** Islamabad Pakistan : s.n., January 2009. Proceeding of 6th International Bhurban Conference on Applied Sciences and Technology, CESAT.
14. **Ranglay, Richard.** *Innovation Reflecting on GPS - GPS System Integration Design & Test.* [Online] Innovation Reflecting on GPS - GPS System Integration Design & Test.html.
15. *Louis Paul Cailletet.* [Online] Wiki Pedia. http://en.wikipedia.org/wiki/Louis_Paul_Cailletet.
16. *Kollsman Window.* [Online] http://aviationglossary.com/avionics-definition/kollsman-window/.
17. *Understanding the altimeter.* **William, Jack.**
18. *Misson to Planet Earth.* Brian Dunbar, Headquarters, Washington, D.C., August, 1992.
19. *HISTORY OF ALTIMETRY. 1960–1992.* **Lefebvre, Michel and Stewart, Robert.** s.l. : Toulous France & Texas A&M University, College Station TX 77845 USA.
20. *NASA Radar Altimeter for the TOPEX/POSEIDON Project.* **R. ZIEGER, ALFRED, et al.** 1991.
21. *The Potential User of GPS Signals as Ocean Altimetry Observable.* **Meehan, Thomas, Young, Larry and Chong Wu, Sien.** Santa Monica, CA : The Institute of Navigation, January 14-16, 1997.
22. **Stephen T. Lowe, Cinzia Zuffada, John L. LaBrecque, Michael Lough,Jesse Lerma & Larry E. Young.** *An Ocean-Altimetry Measurement Using ReflecteGdP S Signals Observed from a Low-Altitude Aircraft.* California : Jet Propulsion Laboratory, California Institute of Technology, Pasadena California 4800 Oak Grove Drive, Pasadena CA, 91 109 M / S 238-600, 1996.
23. *Detecting Bistatically Reflected GPS Signals from Low Earth Orbit Over Land Surfaces.* **Gleason, Scott.** s.l. : Surrey Space Centre, Surrey Satellite Technology Limited Guildford, Surrey GU2 7XH, United Kingdom, 2006.
24. *Acquisition of Reflected GPS Signals for Remote Sensing Applications.* **Dr. M Usman, DW Armitage.** Islamabad : ICAST, 29-30 November, 2008. ICAST 2008.
25. *Experiments of Sea Surface Altimetry Using Reflected GPS Signals.* **Guo, J., Zhang, B. and K. Yang, D.** s.l. : School of Electronic and Information Engineering, Beihang University, Beijing 100083 China, 2011.

26. **James L Garrison, A.K., Valery U Zavorotny, and Stephen J Katzberg.** *Wind Speed Measurement using Forward Scattered GPS Signals.* s.l. : IEEE Transactions on Geo-Science And Remote Sensing, Vol. 40, (No. 1)., 2002.
27. **J.L. Garrison, S.J.K., and M.I. Hill.** *Effect of sea roughness on bistatically scattered range coded signals from the global positioning system.* . s.l. : Geophys. Res. Lett. 25(13): p. 2257-2260.
28. *Towards GPS surface reflection remote sensing of sea ice conditions.* **A Komjathy, J.A.M., V U Zavorotny, P Axelrad and S J Katzberg.** s.l. : Remote sensing for marine & coastal environments.Sixth Int. Conf., 2000.
29. **Zuffada, C. and V. Zavorotny.** *Coherence time and statistical properties of the GPS signal scattered off the ocean surface and their impact on the accuracy of remote sensing of sea surface topography and winds.* s.l. : IGARSS '01. IEEE 2001 International, Geoscience and Remote Sensing Symposium, 2001, 2001.
30. **D Masters, S.K., P Axelrad.** *"Airborne GPS Bistatic Radar Soil Moisture Measurements during SMEX02".* s.l. : Proceedings of IEEE International Geo-science and Remote Sensing Symposium, IGARSS '03, 2003.
31. *GPS Satellite Signal Acquisition and Tracking.* **Johansson, Fredrik, et al.** August 21,1998.
32. **Dinesh Manandhar, R.S., Per-Ludvig Normark.** *"GPS Signal Analysis using LHCP / RHCP Antenna and Software GPS Receiver".* Tokyo. : Centre for Spatial Information Science, The University of Tokyo, Japan.
33. **Dinesh Manandhar, R.S.** *"Signal Analysis using RHCP and LHCP Antenna".*
34. **Antonije R. Djordjevic´, A.G.Z.** *Enhancing the Gain of Helical Antennas by Shaping the Ground Conductor.* . s.l. : IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 5., 2006. .
35. **E. P. Glennon, A. G. D. a. C. R.** *Feasibility of Air Targets Detections Using GPS as a Bistatic Radar.* Sydney, Australia : University of New South Wales.
36. **P., Misra and P., Enge,.** *Global Positioning System. 2001: .* Ganga-Jumana Press. : s.n., 2001.
37. *Detection of Ocean Reflected GPS Signals.* **Katzberg, Garrison J.L. & S.J.** 12-14 Apri, 1997, Theory and Experiment, IEEE Southeastcon Blacksburg'97 Engineering New Century, pp. USA, 290-294.
38. *Carrier Phase Based Ionsphere RecoveryOver A Regional Area GPS Network.* **X, Liao.** Canada : University of Calgary, September, 2000. Department of Geomatics Engineering.
39. *"A 3 GPS-Channels Doppler-Delay Receiver for Remote Sensing Applications".* **O. Nogués, A.S., A. Camps, A. Rius.** Year 2003. Proceedings of IEEE International Geoscience and Remote Sensing Symposium (IGARSS '03).
40. **E. P. Glennon, A. G. D.** *A Review of GPS Cross Correlation Mitigation Techniques.*
41. **Krumvieda, P.M., Chad Cloman, Eric Olson, Dr. John Thomas, Dr. Penina Axelrad, Dr. Wolfgang Kober.** *A complete IF software GPS receiver - A tutorial about the details in 14th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GPS 2001).* Salt Lake City, UT; UNITED STATES. : s.n., 2001 .
42. **Peter Rinder, N.B.** *Design of a Single Frequency GPS Software Receiver.* s.l. : Aalborg University., 2004.
43. **Kraus, J.D.,.** *Antennas 1988: McGraw-Hill International Editions.* s.l. : McGraw-Hill International Editions., 1988.
44. **Wong, H.E.K.a.J.L.** *Characteristics of 1 to 8 Wavelength Uniform Helical Antennas.* s.l. : IEEE Transactions on Antennas and Propagation, VOL AP-28(NO. 2), 1980.
45. **Emerson, D.T.,.** *"The Gain of the Axial-Mode Helix Antenna".* s.l. : Antenna Compendium, Volume 4: p. 64-68., 1995. .
46. *Notes, A., IC MAX2741.*
47. **M. Usman, D.W.A.** *A Remote Imaging System Based on Reflected GPS Signals.* Islamabad, Pakistan. : ICAST, 2006: .
48. *"3D Multistatic SAR System for Terrain Imaging based on Indirect GPS Signals".* **Yonghong Li, C.R., Eugene Donskoi, John Homer, Bijan Mojarrabi.** s.l. : Journal of Global positioning system, 2002, Vols. Vol. 1(No. 1), p. 34-39.

49. **Gleason, S.T.** *Innovation: Reflecting on GPS, Sensing Land and Ice from Low Earth Orbit.* s.l. : GPS World2007, 2007.
50. **Garrison, J.L.** *"Simulation of Wind Speed Retrievals from an Orbiting Bistatic GPS Receiver".* s.l. : IEEE International Geo-science and Remote Sensing Symposium, IGARSS '01., 2001.
51. **O. Nogués, A.S., A. Camps, A. Rius.** *"A 3 GPS-Channels Doppler-Delay Receiver for Remote Sensing Applications".* s.l. : Proceedings of IEEE International Geoscience and Remote Sensing Symposium (IGARSS '03), 2003.
52. **S T Lowe, P.K., G Franklin, J L La Brecque, J Lerma, M Lough, M.R Marcin, R J Muellerschoen, D Spitzmesser, L E Young.** *"A Delay/Doppler Mapping Receiver System for GPS-Reflection Remote Sensing".* s.l. : IEEE Transactions on Geoscience and Remote Sensing, GRS-40 (5), 2002.
53. **Zheng, S.Y.** *Signal Acquisition and Tracking for a Software GPS Receiver.* . Blacksburg, Virginia : Virginia Polytechnic Institute and State University, 2005.
54. **Lei Dong, L.** *IF GPS Signal Simulator Development and Verification, Department of Geomatics Engineering, Calgary.* Alberta, Canada. : The University of Calgary, 2003.
55. **D. Manandhar, R.S.** *"Reflected GPS Signal Analysis and it's Possible Applications".* Tokyo : Centre for Spatial Information Science (CSIS), The University of Tokyo.
56. **Griffiths, H.D.** *Bistatic and Multistatic Radar.* Shrivenham, UK. : IEE Military Radar Seminar. 2004: , 2004.
57. **Griffiths, H.D., Baker, C.J., Ghaleb, H., Ramakrishnan, R. and Willman, E.** *Measurement and analysis of ambiguity functions of off-air signals for passive coherent location.* . s.l. : Electronics Letters, 2003. 39(13): p. 1005-1007.
58. *"Sea and air moving target measurements using a GSM based passive radar".* **Danny K. P. Tan, H.S., Yilong Lu.** Arlington, Virginia, USA. : . in IEEE Radar Conference - RADAR'2005. , May 2005.
59. *Feasibility of Air Target Detection Using GPS as a Bistatic Radar.* **Glennon, E.P.** Sydney, Australia.: Sydney. : University of New South Wales.
60. *Terrain Imaging using a SAR System based on Indirect GPS Signals.* **Yonghong Li, C.R., Eugene Donskoi, John Homer, Bijan Mojarrabi.** s.l. : Wuhan university journal of natural sciences, Vol. 8 No 2B p. 659-664., 2003.
61. *Air target detection via bistatic radar based on LEOS communication signals.* . **Cherniakov, M.N., D. Kubik, K.** s.l. : IEEE Proceedings-Radar Sonar and Navigation. 149(1): p. 33-38., 2002.
62. *Signal detectability in SS-BSAR with GNSS non-cooperative transmitter.* **M.Cherniakov, X.H., T. Zeng.** s.l. : IEEE Proceedings-Radar Sonar and Navigation, 2005. 152: p. 124-132., 2005.
63. *Analysis of space-surface interferometric bistatic radar.* . **Cherniakov, M., Zeng, T., and Plakidis, E.** Toulouse, France. : IGARSS.
64. *Study of BSAR with non-cooperative transmitter.* **M. Cherniakov, R.S., Rui Zuo, M.Antoniou.** Edinburgh. : 2nd EMRS DTC Technical Conference, 2005.
65. *Space Surface Bistatic SAR with Space-Borne Non-Cooperative Transmitters.* **M.Cherniakov, R.S., R. Zuo, M.Antoniou.** s.l. : RADAR 2002: p. 22- 25., 2002.
66. *Results of a space-surface bi-static SAR image formation algorithm.* . **Michail Antoniou, R.S., and Mikhail Cherniakov.** s.l. : IEEE Transactions on Geoscience and Remote Sensing, 45(11): p. 3359 - 3371., 2007.
67. *Improving GPS LI C/A Code Correlation Properties Using a Novel Multi-correlator Differential Detection Technique.* **K. Shanmugam, Surendran.** Canada : s.n., September, 2006. ION GNSS 2006, Fort Worth TX, 26-29.
68. *WITTEX: An Innovative Three-Satellite Radar Altimeter Concept.* **Raney, R. Keith and L. Porter, David.** NO. 11, s.l. : IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, NOVEMBER 2001, Vol. VOL. 39.
69. How Stuff Work's. *How Stuff Work's.* [Online] http://electronics.howstuffworks.com/gadgets/travel/gps1.htm.