Acquisition of BeiDou-2 signal in the presense of Thermal Noise, Doppler Shift and Interfernce

MCS

By

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Abstract

Global navigation satellite systems are enduring for a fast change. GLONASS and GPS which are the oldest satellite navigation system are being revolutionized to meet the current application in the presence of interference, Doppler and thermal noise. Major developments are in the form of increasing the navigation signal frequencies and changing the number of components. In the pursuit for Global navigation operation, Chinese satellite navigation system BeiDou-2 and Europeans satellite navigation system Galileo are under development. China has become the latest entrant into global navigation satellite systems (GNSS) and the research for developing GNSS receivers for BeiDou-2 is experiencing a new upsurge.

With the current functionality of the Beiodu-2 constellation and the promise of the complete Global constellation by 2020, efforts have been focused on the 1561.098 MHz B1I signals for the software receiver implementation. In this thesis the acquisition of Beiodu-2 software receiver is implemented by evaluation of Cross Ambiguity Function CAF by FFT based Coherent Parallel Code Search scheme in the presence of Interference, Doppler and Thermal Noise.. The DVB-T device along with active antenna is configured as a front end which provides the digital samples of BeiDou to the host computer for software receiver implementation in terms of the acquisition of Beiodu-2 satellites. The results have been verified by analyzing the sky plots of Beiodu-2 B1I signal of particular sites where Beiodu data was collected.

In addition, a Beiodu-2 B1I GNSS signal generator is designed and implemented in Matlab which is to be used for algorithm development and testing. The BeiDou-2 software acquisition part of the receiver is implemented in Matlab and is capable of performing BeiDou satellite acquisition on both actual and simulated data with extreme properties.

Interference, Doppler and Thermal noise are the major concerns facing the BeiDou GNSS applications and are important parameters which describes the BeiDou receiver performance. In this thesis the post-correlation carrier to noise ration CNR and carrier to interference ratio CIR for the BeiDou-2 B1I signal is analytically derived. Monte Carlo simulations have been employed to develop the simulation model for the Beiodu-2 receiver acquisition performance. The agreement between theoretical and simulation results supports the validity of the Algorithm.

DEDICATION

In the Name of Allah, the most Merciful, the most Beneficent.

Dedicated to my Father Lt Col Muhammad Aslam Baloch (Late) who is not with us but his Sincere Prayers and Guidance have been the motivating forces for my success. May Allah grant his soul eternal peace and may his grave be an abode of light.

ACKNOWLEDGMENTS

I feel a deep sense of gratitude to express my thanks to the Almighty ALLAH, the Most Merciful and the Most Beneficent, Who gave me strength to accomplish the ordeal task of completing this work. The kind, the merciful, the compassionate whose blessings conferred me knowledge, wisdom, guidance, health and renowned teachers to approach this destination successfully. All salutations be upon The Holy Prophet MUHAMMAD (Salalla-Ho-Alaihe Wasallam) who ordained every Muslim to seek for knowledge from cradle to grave.

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Last but not least, no acknowledgement would ever adequately express my obligation to my mother, wife Maria and all family members who always stood by me.

Their great devotion, moral support, love and encouragement provided me vigor to fulfill this task.

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KEY TO ABBREVIATIONS

AWGN	Additive White Gaussian
BDS	BeiDou Satellite Navigation System
BOC	Binary Offset Carrier
BPSK	Binary Phase Shift Keying
CAF	Cross Ambiguity Function
CA	Coarse Acquisition
CDMA	Code Division Multiple Access
CIR	Carrier to Interference Ratio
ICR	Interference to Carrier Ratio
CNR	Carrier to Noise Ratio
DSSS	Direct Sequence Spread Spectrum
DVB-T	Digital Video Broadcast Terrestrial
FDMA	Frequency Division Multiple Access
GEO	Geostationary Earth Orbit

GPS	Global Positioning System
IF	Intermediate Frequency
IFFT	Inverse Fast Fourier Transform
IGSL	Inclined Geostationary Earth Orbit
ILS	Instrument Landing System
LO	Local Oscillator
LORAN	Long Range Navigation System
LOS	Line of Sight
MEO	Medium Earth Orbit
MLS	Micro Wave Landing System
NAV	Navigation
NH	Neumann-Hoffman
PVT	Position, Velocity and Time
QPSK	Quadrature Phase Shift Key

Chapter 1

Introduction

The term navigation is stated as the science of getting a person or a craft from one point to another and in our daily lives we all conduct some form of navigation which may cover driving to the office, stores, schools and colleges using fundamental navigation skills like landmarks , common sense, eyes etc. However, most of the cases where more detailed information is required like accurate knowledge of the desired course, transit time to the desired location and exact knowledge of our position then navigational aids other land marks are employed. Such navigational aids can be in the form of simple clock to estimate the time to the destination or can be the odometer to keep track of the covered distance. Some other navigational aids which are more complex and transmit electronic signals are called radio navigation aids[1].Position of a person can be computed by using signals from different radio navigation aids. Some radio navigation aids are capable of finding out the time dissemination and the velocity. It is pertinent to mention that it is the user's receiver which carry out processing of the received signals and compute the position .The receiver acquire the signals and then compute the range, bearing and estimated TOA for navigating to a desired location[2]. Different types of navigation aids exist and are categorized as space-based or ground based.

Global navigation satellite systems are enduring for a fast change. GLONASS and GPS which are the oldest satellite navigation system are being revolutionized to meet the current application in the presence of interference, Doppler and thermal noise. Major developments are in the form of increasing the navigation signal frequencies and changing the number of components[3]. In the pursuit for Global navigation operation, Chinese satellite navigation system BeiDou-2 and Europeans satellite navigation system Galileo are under development. In this Thesis we will focus on the space based navigation aid which is the BeiDou-2 Global Navigation Satellite System of China and will cover the simulation and acquisition of BeiDou-2 B1I signal using FFT based Coherent Parallel Code Acquisition scheme in the presence of interference, thermal noise and Doppler.

1.1 Overview of BeiDou Global Navigation Satellite system

The BeiDou Navigation satellite system is a part of China satellite program and comprises two separate constellations, one is operating since 2000 and providing regional services (mainly customers of china) and providing the limited applications by using the constellation of three satellites and another Satellite Program for Global Navigation service is currently under development[7] .Officially called BeiDou-2 or Compass will be the Global Navigation Satellite System and will be comprised of the constellation of 35 satellites. Beiodu-2 System will start providing Global navigation services by 2020.BeiDou is a Chinese word which means Big Dipper Constellation. The literally name of BeiDou is Northern Dipper, which are the brightest seven stars of Ursa Major Constellation primarily used for the navigation.

On completion, the space constellation will blanket the earth with five Geostationary Earth Orbit (GEO) satellites operative at the altitude of 36,786 Km, twenty-seven Medium Earth Orbit (MEO) satellites operative at the altitude of 21,528 km and three Inclined Geosynchronous Satellite Orbit (IGSO) satellites operative at the altitude of 35,786 km with inclination of 55 degrees to equatorial plane. BeiDou GNSS is operating on DS-CDMA principle. The constellation of BeiDou GNSS is the mixture of GEO,MEO and IGSO which provide improved observation geometry for positioning and determination of orbit as compared to GPS , GLONASS and Galileo[4,8]. Fig 1.1 shows the tracks of BeiDou Satellites.

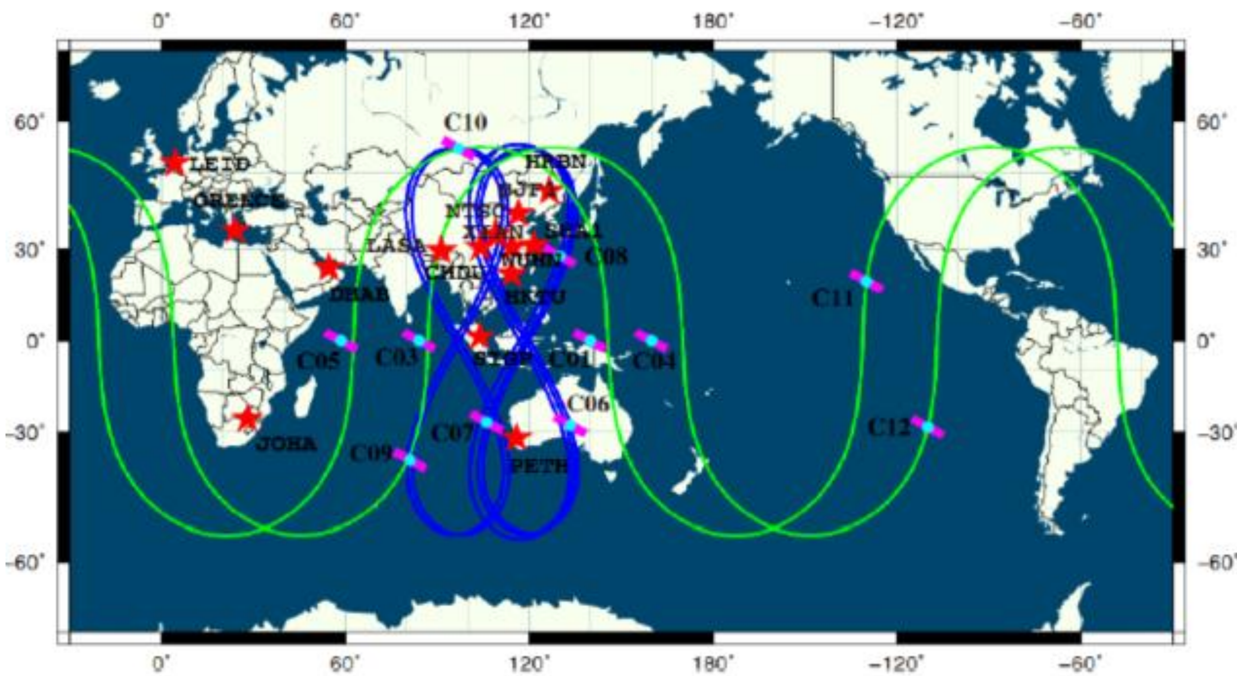


Fig 1.1 Tracks of the sub-satellite of 4 GEO , 5 IGSO and 3 MEO satellites.

In order to address the growing demands of the customers in terms of reliability, accuracy and availability, BeiDou system is bringing up new enhancements like introduction of NH Code, Modulations and signal structures. BeiDou system will allow users everywhere in the world to have information of Position, time and velocity. The BeiDou system has the extremely stable timing system on board of the satellites which is composed of synchronized atomic clocks with extremely accurate ground based reference timing system[9]. Transit time of a signal from the satellite to the user is calculated through the same clocks with high degree of precision. By using four satellites, four transit times can be estimated. Furthermore the navigation message contains the details of the orbit and allow the user to find out the time and position in 3D.

1.2 BeiDou Operation

Positions are obtained using the known characteristics of the propagation of radio waves. The idea of Radio navigation started with invention of Loran system (Long Range Navigation System) in WW II and afterwards speeded up with the introduction of short range LOS (line of sight) navigational aids like MLS (Micro wave landing system), VOR (VHF Omni directional radio range) and the Instrument Landing System ILS(Instrument Landing System) [1].

Trilateration is the assessment of the location which is based on distance measurements to the reference points at known locations . Distance is measured with the help of TOA (Time of Arrival), which is the time taken by the signal to propagate from transmitter to the receiver and velocity of speed of the propagation of wave[10].

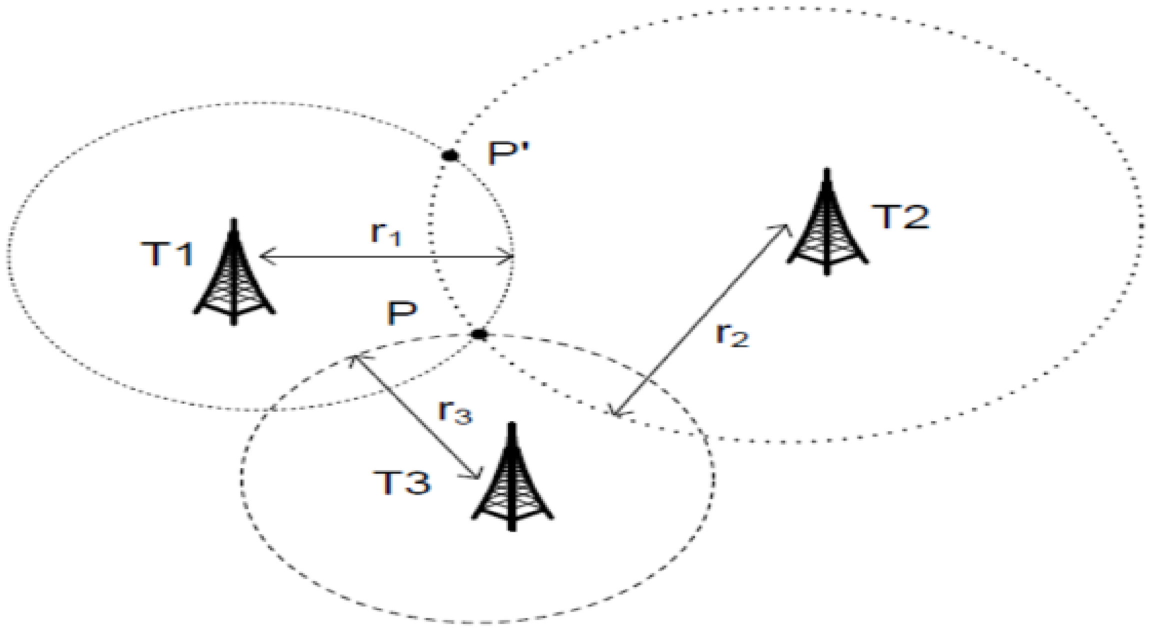


Figure 1.2.Trilateration. Estimation of the distance from the three transmitter at known location allows the observer to find its position, point P.

As given in Fig 1.2 that if one can estimate the distance of three transmitters from the known location then one can easily find out its own position. By measuring the range of the observer from the T1 Transmitter of known location, the observer position will be determined which should lie in the circle of radius r1 which is centered at T1. Range of the observer from the 2nd Tower T2 with known location gives the circle with radius r2 , thereby dropping the uncertainty of the observer position from two points where there is a intersection of the circle . On the basis of physical information, one of the point can be discarded. By measuring the range from the 3rd transmitter tower T3 will unambiguously conclude the observation location, point P.

Angle of elevation between at least one of the transmitters and the observer is required to be large for extending the system to a 3-D solution. As the ground based transmitters have the limited height so the solutions which are obtained from them are limited to 2-D solutions. Each range measurement of a satellite based transmitter would end in the line of position which describe the sphere geometry, whose surface represents the possible position area. Intersecting Spheres of three transmitters would identify the coordinate in 3-D at the earth surface. In triangulation we deal with angles and in tri-literation we deal with distances[11].

BeiDou Global Navigation satellite system is TOA system which is based on Trilateration. In order to find out the position, it is essential that knowledge about the orbit and nature of the satellites which are visible to the GNSS receiver be informed at the time when solution is made. The speed of BeiDou satellites in space is approximately 3900 meters per second at an approximately orbital radius 27000 km, even then their location can be accurately estimated. Using the nearly perfect atomic clock on the satellites which are nearly perfect synchronized, the transmission times are stamped on BeiDou signals which provide the civilian users with horizontal and vertical positioning accuracy within 10 meters, 0.2-meter-per-second velocity accuracy and timing accuracy within 50 nanoseconds[12,14] .

1.3 Comparison of B1I signal of BeiDou2 with Legacy L1 of GPS

In Dec 2013 China Satellite Navigation Office has released the BeiDou navigation satellite system signal in space interface control document(version 2.0) which will assist researchers to design the GNSS receivers of B1I. The characteristics of BeiDou B1I signal can be compared with legacy L1 signal of GPS, comparison of both signals are given in the following table:

Parameters	**B1I**	**L1**
Code Size	2046 chips	1023 chips
Carrier	1.561 GHz	1.57542 GHz
Modulation	QPSK	BPSK
NH Code	Yes	No
CodeFreqency	2.046 Mcps	1.023 Mcps

Table.1.1 Comparison of B1I and Legacy L1 Signal

In order to to improve the positioning performance of BeiDou , 2nd layer of modulation is added between the PRN code and Navigation data which is called Neumann-Hoffman (NH) code modulation as shown in Fig 1.3. The important task of NH Code includes spectral separation , protection against narrow band interference and bit synchronization[13].

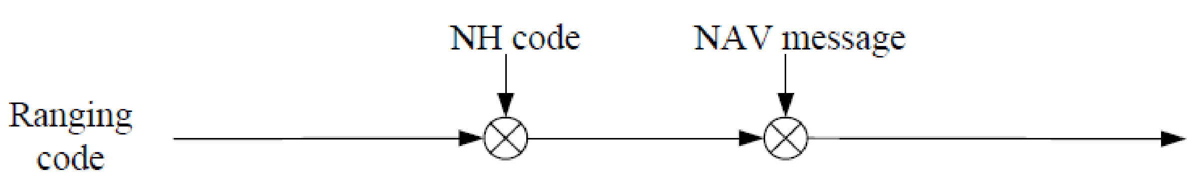


Fig 1.3 The Addition of NH Code mode in legacy GNSS Transmitter.

The PRN code of the Beiodu-2 B1I signal is a 2046 bit sequence which is deterministic and called pseudorandom noise code (PRN code) or pseudorandom binary sequence code (PN Code) and when BeiDou-2 B1I PRN code is transmitted at the rate 2.046 Mega chips per second (MCps),it repeats at every millisecond. In case of GPS, the legacy signal L1 has the 1023 bit sequence of C/A code and transmitted at the rate of 1.023 mega chips per second (Mcps).These pseudorandom binary sequences only correlate or match up strongly when they are exactly aligned. Precision code is the P Code which is primarily used for military purpose. China is offering P code to only Pakistan Military and People's Liberation Army. Correlation gain is increased due the extreme length of Precision code. Firstly Receiver would lock onto the simple C/A code and after obtaining the position and current time it will synchronized with the P-code[7].

1.4 Problem statement

With the current functionality of the BeiDou-2 Chinese Global Navigation satellite system constellation, efforts have been focused on 1561.098 MHz B1I signals for BeiDou software receiver implementation .Acquisition of Beiodu-2 B1I signal is required to be carried out by evaluation of Cross Ambiguity function using the FFT based Coherent Parallel Code search scheme and in addition BeiDou-2GNSS signal generator is also required to be designed and implemented in MATLAB for algorithm development and creating a realistic environment for testing of algorithm in the presence of Thermal Noise , Doppler and Interference.

1.5 Review of the Literature

Previous research work which is relevant to the work done of this thesis is given in this section .BeiDou-2 GNSS Receiver can be divided into four major parts[6,14].

a. The Front-end: The B1I signal of BeiDou-2 of carrier frequency 1.561098 GHz is received from the satellite and down converted to intermediate frequency and then sampling of the frequency is carried out as digital input is required for baseband processing of the signal for the acquisition block.
b. Acquisition: It is the 3D search which is carried for all PRNs and find out the Doppler Frequency, code delay and all visible satellites.
c. Tracking: Monitoring of changes in code delay and Doppler are undertaken by tracking process.
d. Computation of a Position: After tracking the signal, position of the satellite is computed by decoding the navigation message bits.

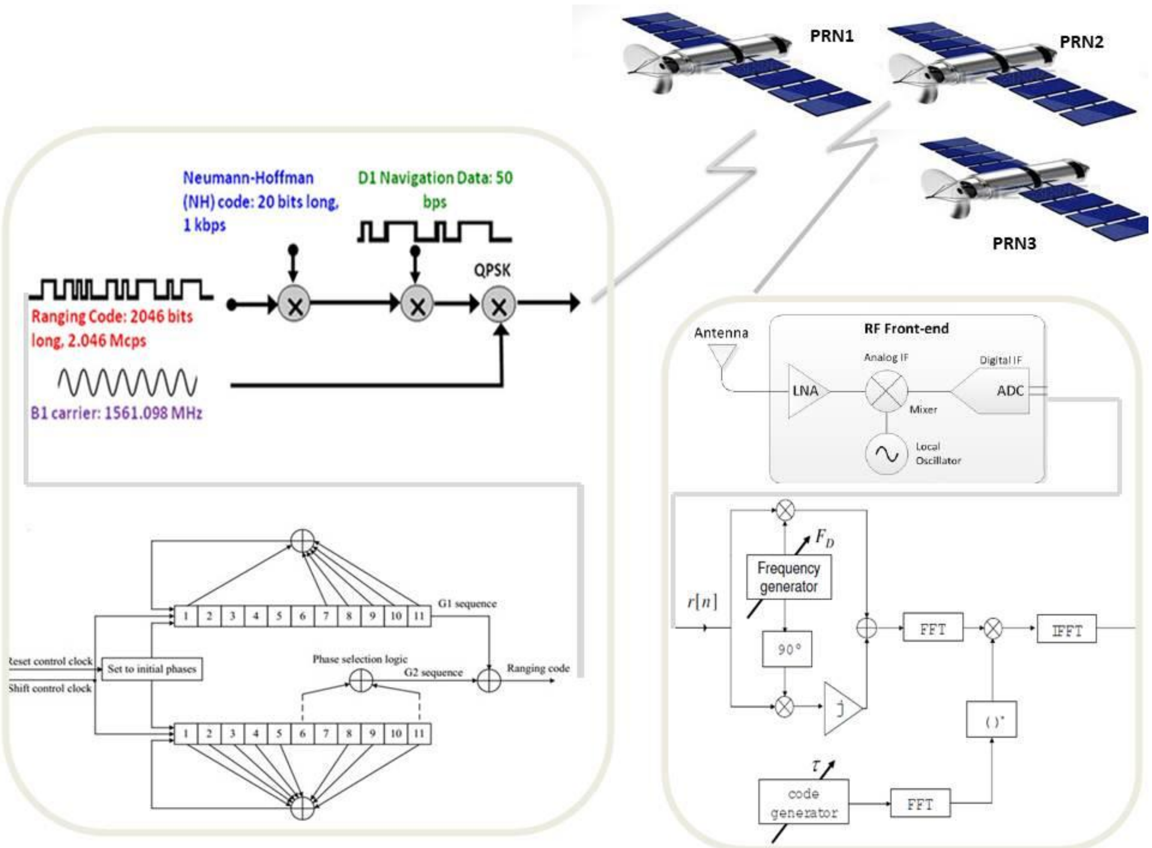
The main objective of the acquisition process is to find out the Doppler and code delay for all visible satellite. After receiving the signal from the satellites, it is firstly down converted and sampled by the front end. A three Dimensional search is carried out on all PRNs to find the satellites which are visible and corresponding Doppler effects and code delays. It is done by multiplying the incoming signal by a carrier which correspond to the approximate frequency of a signal which is received and spreading code local replica. This search is carried out for all code delay (2046 chips in case of BeiDou-2 B1I) and Doppler range between -5KHz to +5KHz. These Multiplications are realized in frequency domain using the Fast Fourier Transform in case of software receivers [15].

In order to carry out coherent acquisition, the increment of the Doppler which is locally generated has the dependence on acquisition time, frequency bin size is smaller for longer acquisition time. In order to acquire the weak GNSS signals like foliage , indoor and urban canyon, the acquisition time is required to be increased but due to the size of sampled vectors to correlate and number of frequency bins the signal processing time is rapidly increased. In fact when there is increase of acquisition time, the frequency bin numbers are also required to be increased to acquire the signal [16]. An FFT-based signal acquisition technique is implemented in the software receiver [3].

Non-coherent correlation (squaring the correlate outputs) can be used to acquire the low power signals. In this the size of the frequency bin is not required to be changed but the performance is not satisfactory in terms of signals to noise ratio (SNR) as with the coherent integration due to the increasing noise. Such techniques allow acquisition of signals attenuated upto 20 dbs. In general, following parameters determines the acquisition performance [17]:

a. Acquisition Mean Time: Time taken by the receiver to correctly detect the signal.
b. Probability of Detection: Probability of correctly finding out the GNSS signal and estimating the code delay and shift in Doppler.
c. Probability of False alarm: Probability of wrongly determine the presence of a Signal.

1.6 System Model



Space Segment GNSS Receiver

Fig 1.4 System Model Diagram showing the space segment of Beiodu-2 and Acquisition module of Beiodu-2 GNSS receiver.

System will be using 11-bit Gold Code Generator for Generating ranging codes of Length 2046 Chips at the rate of 2.046 Mcps and carrier frequency of 1561.098 MHz Figure 1.4 shows the system model which will be implemented in this thesis , we will be covering both the space and ground segment. Each of the module is covered in detail in Chapter 5. We will design a GNSS Signal generator of Beiodu-2 B1 signal and will also carry out the performance based acquisition on both actual and simulated data of Beiodu-2 B1I signal in the presence of thermal Noise, interference and Doppler.

1.7 Objectives and Motivations

The principle objective of this thesis is to carry out complete and cohesive analysis of the Acquisition of BeiDou-2 B1I signal in the presence of interference, Doppler and thermal noise. Matlab is used for implementation of algorithm, sequence of goals are as under:

a. Collection of Beiodu-2 data from the Front end and providing samples to the host computer for baseband processing.
b. Implementation of algorithm for acquisition ofBeiDou-2 B1I signal based on evaluation of CAF (Cross Ambiguity Function) using FFT based Coherent Parallel Code Phase Search scheme in the presence of noise , interference and thermal noise.
c. Performance measurement of the Acquisition algorithm in the presence of thermal noise, interference and Doppler by simulation of BeiDou-2 B1I signal using Matlab.
d. Carrying out of Monte Carlo simulations to study the effects of CNR (Carrier to noise ratio) and CIR (Carrier to interference ratio) on the Acquisition performance of BeiDou-2 receiver.

1.8 Methodology

Collection of actual data will be carried at the Islamabad, Pakistan by using Device DVB-T along with active antenna as a Frontend tuned up on Frequency 1561.098 MHz. Acquisition of Beiodu-2 B1I signal will be carried out by evaluation of CAF using Coherent parallel code phase acquisition scheme in the presence of Thermal Noise, Doppler and Interference and same will be implemented in Matlab. Simulation of Beiodu-2 B1I signal will also be carried out using Matlab in which power level of different Beiodu-2 satellites and Doppler can be varied with an option of addition of AWGN. Results of Collected actual data will be verified through sky plots and overview of Beiodu-2 tracks .

1.9 Thesis structure

Chapter 2 gives an overview of the DSSS and signal structure of B1I in detail with mathematical representation of the signal. Chapter 3 gives an insight view of the Cross ambiguity function evaluation methods and detection strategy with emphasis on mathematical modeling. Chapter 4 gives the effects of interference and thermal noise on Beiodu-2 GNSS acquisition. Chapter 5 Gives the details of simulation and acquisition of the Beiodu-2 B1I signal by evaluation of CAF using FFT based Coherent Parallel code phase search scheme and implementation of Gold code generator of B1I . In order to carry out the performance based verification, Beiodu-2 GNSS generator is also implemented. Chapter 6 gives the simulations and results in which the acquisition of actual and simulated data of Beiodu-2 in the presence of Doppler , interference and thermal noise is carried out. For performance based measurement, Monte Carlo simulations of carrier to noise ration and Carrier to interface ratio with respect to acquisition performance is also drawn. Finally Chapter 7 draws the conclusion of this Thesis and gives recommendations for future work.

Chapter 2

Direct Sequence Spread Spectrum and BeiDou Signal

2.1 Introduction.

In this Chapter the DSSS and BeiDou-2 B1I Signal model is covered with mathematical modeling of the BeiDou signal. In general the Global Navigation Satellite systems (GNSSs) are direct sequence spread spectrum systems (DSSS) in which the spreading codes having cross-correlation / good correlation properties and are used to spread the navigation message and measuring the time of transmission from satellite to the receiver. Different satellite constellations broadcast different spreading sequences which are quasi-orthogonal meaning that the cross-correlation between different spreading sequences is almost zero. In this optics. Systems like Chinese BeiDou ,US GPS and European Galileo are DS-CDMA systems , whereas the GLONASS which is a Russian Global Navigation satellite system is using FDMA system to differentiate a signal from other GNSSs[17, 18].

2.2 BeiDou Signal Structure

The carrier frequency B1I of BeiDou-2 is 1561.098 MHz and is coherently derived from the satellites based frequency source .QPSK modulation is carried out on Ranging code, NH Code and NAV Message Signal[8].

2.2.1 NAV Message

DS-CDMA is the multiplexing mode of the signal B1I.Formatting of D1 and D2 NAV message is carried out basing on their rate and structure. Data rate of D1 NAV message is 50 bps which is modulated with secondary code of 1kbps. Basic NAV info is contained in D1 NAV message which includes all satellites almanac and fundamental NAV information. Data rate of D2 NAV message is 500 bps and it includes the basic navigation information like ionosphere grid information and the BDS integrity. MEO/IGSO satellites broadcast NAV message in D1 format and GEO satellites broadcast NAV message in D2 format[8].

2.2.2 Neumann-Hoffman Code

The Neumann-Hoffman (NH) code is modulated on a ranging code for a D1 message of data rate 50 bps. The NH code period is selected as per the NAV message bit duration that the duration of one bit of NAV message is 20 ms and is equal to the duration of the period of NH Code which is 20 bit long code (0, 0, 0, 0, 0, 1, 0, 0, 1, 1, 0, 1, 0, 1, 0, 0, 1, 1, 1, 0). One bit duration of NH code is 1ms and rate of 1kbps is adopted. Ranging code period is 1ms which is equal to the one bit duration of NH code. It is the second layer of modulaton which is added on ranging code. The important task of NH Code includes spectral separation , protection against narrow band interference and bit synchronization [8,13].

2.2.3 Pseudo-Random Noise

PRN are the sequences which are used to spread the signals and identification of different satellites are carried out with the help of PRN numbers. The time taken by the GNSS Signal to reach the receiver is estimated by exploiting the correlation properties of the spreading sequence. In Fig 2.1, basic principle of DS-CDMA is shown in which Pseudo-random noises of different satellites are transmitting. In case of BeiDou-2 Gold code Generator is used by employing 11 bit shift register. PRN Sequence of each satellite is different from the other and same facilitates the receiver to differentiate the different satellites [19].

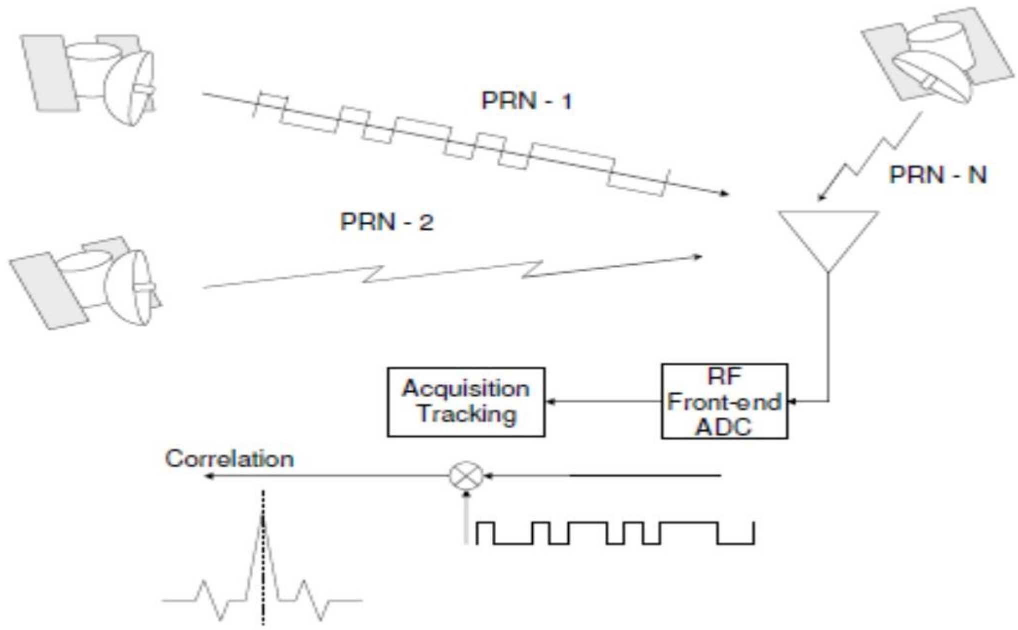


Fig 2.1 . Different BeiDou Satellites are transmitting different PRN sequences and by exploiting the correlation properties of the different spreading sequences , the transit time is estimated.

2.3 Mathematical Modeling of GNSS Signal

In an environment of one-path additive Gaussian noise, the input signal at the Receiver can be written as:

$$rRF = \sum_{I=1}^{L} yRF\ (t) + \eta RF(t) \tag{2.1}$$

Which is the sum of L useful signal transmitted by L number of satellites and $\eta RF(t)$ is the noise term. Following structure is assumed by the useful signal

$$y_{RF,i}(t) = A_i C_i\,(t - \tau_{i,}^{a}o) d_i(t - \tau_{i,}^{a}0)\cos[2\pi(fRF + f_{d,0,}^{i})t + \phi i, 0] \tag{2.2}$$

A_i is the amplitude of the useful i th signal.

$\tau_{i,}^{a}o$ is the delay introduced by communication channel.

$f_{d,0,}^{i}$ is Doppler frequency which is affecting the ith useful channel.

$\phi i, 0$ is a random phase.

fRF is the frequency of the carrier and different GNSS have different frequencies, for BeiDou system B1I signal has fRF =1561.098MHz.

$C_i(t)$ is defined as the spreading sequence.

$d_{i\,(t)}$ is the NAV message.

$ci(t)$ which is the spreading sequence and can be expressed as:

$$C_i(t) = C_{1,i}(t) C_{2,i}(t) s_{b,i}(t) \tag{2.3}$$

where $C_{1,i}(t)$ code is defined as the periodic repetition of primary secondary code, $C_{2,i}(t)$ is the secondary code and $s_{b,i}(t)$ is defined as signal of subcarrier. The subcarrier $s_{b,i}(t)$ is defined as the periodic repetition which belongs to the basic wave and determines the spectral characteristics of $y_{RF,i}(t)$. Binary offset carrier (BOC) and Binary phase shifting key (BPSK) are the two examples of subcarrier signals[9]. Figure 2.1 shows the basic waves which generate those sub carrier. GPS Coarse Acquisition (C/A) adopts BPSK and consists in the pulse duration T_H *which is constant.* $s_{b,i}(t)$= 1 islead by the BPSK basic wave due to the periodic repetition. New GNSSs like BeiDou and Galileo, the more complex modulation have been used like in case of BeiDou System ,QPSK modulation is used[16,17].

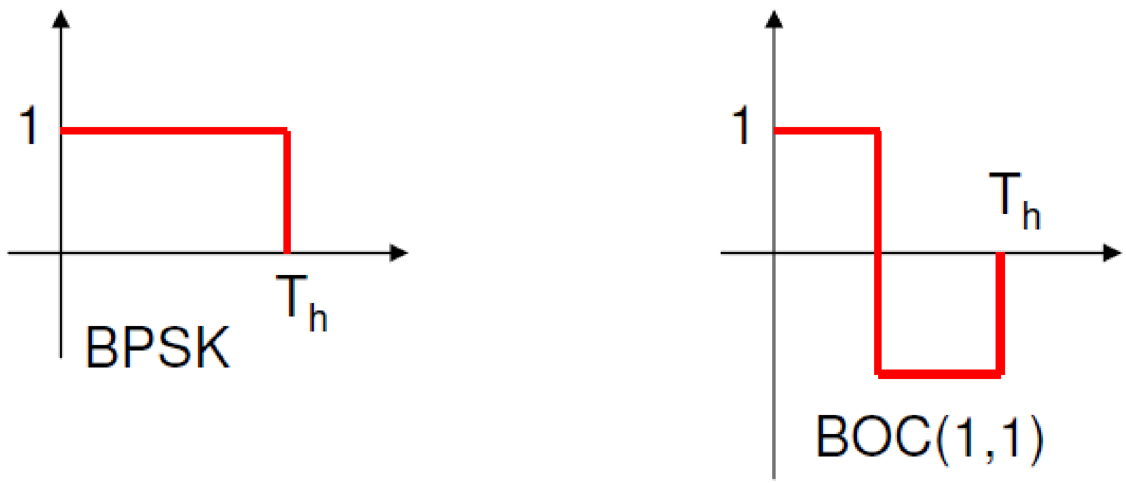


Fig 2.2 Examples of subcarrier signal generated by basic pulses.

$\eta RF(t)$is assumed to be AWGN (Additive White Gaussian Noise) with PSD (power spectral density) $N_O/2$

$y RF, i(t)$which is the useful signal is characterized by power

$$C_i = A_i/2 \quad (2.4)$$

Quality of a signal is measured by the power to noise density ratio of the carrier $c_i = N_O$. The input signal at the GNSS receiver is received by the antenna and then front end down converts and filter the incoming received signal. For baseband processing, signal is converted into digital form. Before its AD conversion, the receive signal is given by

$$r\ (t) = \Sigma_{i=1}^{L} y_i(t) + \eta(t)$$

$$=\Sigma_{i=1}^{L} A_i C_i\ (t-\tau_{i,}^{a}\mathrm{o}) d_i\big(t-\tau_{i,}^{a}0\big)\cos[2\pi\big(fIF+f_{d,0,}^{i}\big)t+\phi i,0]+\eta(t) \qquad (2.5)$$

where intermediate frequency of the receiver is fIF. Spreading sequence is defined by the term $C_i\ (t-\tau_{i,}^{a}\mathrm{o})$ and is filtered by frontend of receiver.

$$\check{C}_I\,(t) \approx c_i(t) \qquad (2.6)$$

This is the simplified condition which is assumed and the impact of the frontend filter is neglected. $\eta(t)$ is the filtered noise component and down converted.

Finally the Eq. (2.5) is digitalized and sampled. Following signal model is obtained when we neglect the quantization impact:

$$r\ (nT_S)= \sum_{I=1}^{L} \mathcal{Y}_i\ (nT_s) + \eta(nT_s)$$

$$=\Sigma_{i=1}^{L} A_i C_i\ (nT_s-\tau_{i,}^{a}\mathrm{o}) d_i\big(nT_s-\tau_{i,}^{a}0\big)\cos[2\pi\big(fIF+f_{d,0,}^{i}\big)nT_s+\phi i,0]+\eta(nT_s) \qquad (2.7)$$

Sampling of a continuous time signals $x(t)$ with the sampling frequency $f_s = 1/Ts$ gives the $x(n)$ which is defined as the discrete-time sequence and given by the notation $x(n) = x(nT_s)$ due to this reason equation 2.7 can be rewritten as:

$$r\ (n)= \sum_{I=1}^{L} \mathcal{Y}_i\ [n] + \eta(n)$$

$$= \Sigma_{i=1}^{L} A_i C_i\ (n-\tau_{i,}^{a}\mathrm{o}\ /\ T_s) d_i\big(n-\tau_{i,}^{a}0\big)\cos[2\pi\big(fIF+f_{d,0,}^{i}\big)nT_s+\phi i,0]+\ \eta(n)$$

$$= \Sigma_{i=1}^{L} A_i C_i\ (n-\tau_{i,0}\ ) d_i\big(n-\tau_{i,0}\big)\cos[2\pi\, F_{D,0}^{i} n+\phi i,0]+\ \eta(n) \qquad (2.8)$$

Where $F_{D,0}^{i} = \big(fIF+f_{d,0,}^{i}\big)T_s$ and $\tau_{i,0} = \tau_{i,}^{a}0\ /\ T_s$

The $\eta(n)$ Spectral characteristics depends upon the adoption of decimation strategy, type of filtering and the sampling by the frontend. Appropriate choice is the sampling of IF signal with the sampling frequency $f_s = 2\ B_{IF}$ (B_{IF} is the bandwidth of front end).

$\eta(n)$ is the wide sense stationary process (WSS) .As the code is orthogonal, the receiver will separately analyze the useful signals of GNSS and thereby the single satellite case is considered and the index i is dropped[12].

The resulting signal is

$$r\ (n) = y[n] + \eta(n) = Ac\ (\ n - \tau_0)\ d(\ n - \tau_0) \cos[2\pi\ F_{D,0}n + \phi_0] + \eta(n) \qquad (2.9)$$

Where

A is the amplitude of the BeiDou-2 B1I signal.

η is assumed to be AWGN (Additive White Gaussian Noise)

$C$is defined as the spreading sequence.

$d$is the NAV message.

$\phi_O$is a phase.

2.4 Summary

Beidou-2 B1 Signal is DS-CDMA system and due to different PRN sequences generated by 11 bit Gold code generator employed at the BeiDou satellites facilitate the BeiDou-2 GNSS Receiver to differentiate the signal from the other constellations. Due to the addition of Neumann Hoffman code in BeiDou-2 B1I Signal as a secondary code provides the spectral separation , protection against narrow band interference and bit synchronization.

Chapter 3

GNSS Signal Acquisition

3.1 Introduction

In this chapter a general acquisition system is explained as the interaction of different functional blocks performing different logical operations. The framework developed by this chapter will facilitate us in selecting the efficient acquisition method for BeiDou-2 B1I Acquisition .Different Acquisitions system and their application covered in the literature[1,20,21,22] are based on the processing and evaluation of Cross Ambiguity Function(CAF) and is covered in detail in this chapter.

3.2 Basic concepts

Signal acquisition is the first step which is performed by the GNSS receiver and it carries out the three dimensional search which include the presence or absence of the requisite GNSS signals and then provides the rough estimate of the Doppler frequency and code delay of the signal. Some results which are well known of the detection and estimation theory are implemented and different functional and logical blocks are made part of the acquisition process. In the literature of GNSS, the major roles of these functional blocks and these disciplines are sometimes unclear. A general acquisition system is given as the interaction of four logical operations[16,17]. Acquisition system is based on the processing and evaluation of CAF (Cross Ambiguity Function). In discrete time domain, it can be given as :

$$Y(\tau, F_D) = \frac{1}{N}\sum_{n=0}^{N-1} r[n]c[n-\tau]\exp\{-j2\pi F_D n\} \quad (3.1)$$

In this equation ,the received signal is $r[n]$ and $c[n-\tau]$ is defined as the local replica which is reproducing the secondary code , the sub carrier and PRN code.$F_D$is the Doppler frequency and τ is the code delay of the BeiDou GNSS receiver. In the ideal case of acquisition, CAF (Cross Ambiguity Function) should give the Sharp peak which should belong to the values of Doppler Frequency $F_D$and the code delay τ . Noise and other impairments can have adverse effects on the CAF readability and same warrants the further processing. Only envelop of the CAF is observed in non-coherent acquisition and phase dependence is avoided.

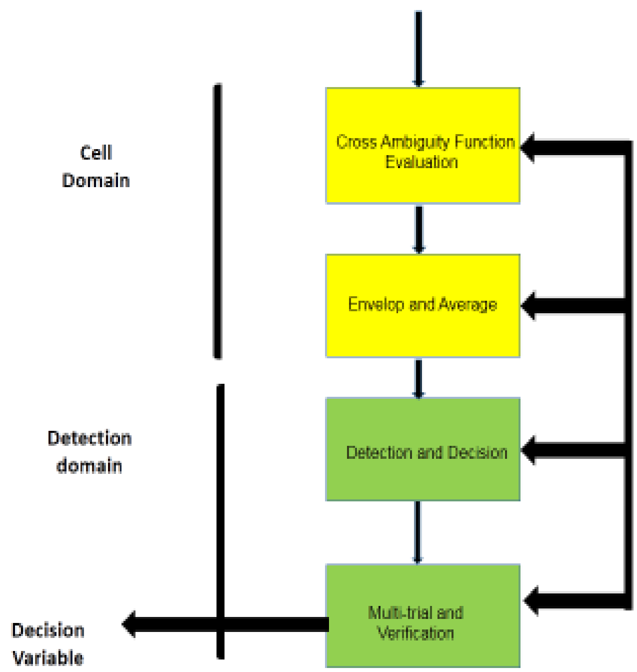


Fig 3.1 Acquisition process is covered in the given steps and this figure depicts the conceptual representation which starts from the input signal and lead to the estimation of code delay and Doppler Frequency.

In order to reduce the noise, coherent and non-coherent integrations can be employed. Making up of decision regarding the presence of satellite is done by evaluating the averaged CAF envelop. Number of detection strategies can be employed and some of them are based on partial knowledge of the CAF. Further enhancement of detection can be carried out by the multi-trial techniques .Figure 3.1 gives the four functional blocks of acquisition system and depicts the general acquisition scheme

a. CAF evaluation
b. Envelope and Average
c. Detection and Decision
d. Multi-trial and Verification

First and second stage form part of the evaluation of CAF and the third and fourth stage find out the absence or presence of the signal and carry out verification that signal has been taken correctly or not. All stages are interlinked and these interconnections are given in Fig 3.1. Working of these functional blocks are given in detail.

3.3 CAF evaluation

CAF evaluation as given in equation (3.1) is the first stage of Acquisition. $r[n]$is the received signal at frequency $F_D = (f_{IF} + f_d)T_s$, the $r[n]$is multiplied by the two orthogonal sinusoids with the aim of converting the received signal into the baseband signal and to remove the Doppler shift effects. As a result two new signals are generated

$$Y_c\,(n, F_D) = r[n] \cos(2\pi F_D\, n)$$

$$Y_s\,(n, F_D) = r[n] \sin(2\pi F_D\, n) \qquad (3.2)$$

Multiplication of $r[n]$ with the two orthogonal sinusoids is the eq 3.1 complex modulation, which is implemented in the receiver by splitting the signal into two and carry out multiplication by cosine and sinusoids. Intermediate frequency f_{IF} and local Doppler frequency f_d are the two terms which are given in normalized frequency.

$$F_D = (f_{IF} + f_d)T_s = (f_{IF} + f_d)/f_s \tag{3.3}$$

f_{IF} is the known intermediate frequency and it depends upon the receiver architecture whereas f_d is selected.

$$f_d = f_d min + l\Delta f \quad \text{for } l = 0; 1 \ldots\ldots L\text{-}1: \tag{3.4}$$

In order to find out the Doppler shift of the incoming signal ,number of different Doppler frequencies are given like in low dynamic application the given range is $\pm$ 5 kHz. Δf is the Doppler step and its normalized counter part $\Delta F = \Delta f/fs$ and both are selected to avoid the maximum loss due to Doppler residual errors[23].Multiplication of the signals $Y_c'(n, F_D)$ and $Y_s'(n, F_D)$ is carried out with the replica of PRN code $c1[n]$, secondary code $c2[n]$, the subcarrier $sb[n]$. delaying the signal replica by τ and the following signals are obtained :

$$Y_c'(n, F_D) = r[n]\cos(2\pi F_D n)c[n-\tau]$$

$$Y_s'(n, F_D) = r[n]\sin(2\pi F_D n)c[n-\tau] \tag{3.5}$$

τ is the delay taken from the set

$$\tau = \tau\, min + h\Delta\tau \qquad \text{for } h = 0,1\ldots \text{H-1} \tag{3.6}$$

Different delays are tested and after that Acquisition block is able to find out the estimate of the delay of the received signal $r[n]$.

$$Y_{I(\tau,F_D)} = \frac{1}{N}\sum_{n=0}^{N-1} Y_c' \, (n,\tau,F_D)$$

$$Y_{Q(\tau,F_D)} = \frac{1}{N}\sum_{n=0}^{N-1} Y_s' \, (n,\tau,F_D) \tag{3.7}$$

In equation 3.7 ,for evaluation of in-phase and quadrature components, N (numbers of samples) are used and define the coherent integration time.

$$T_C = \; NT_S \tag{3.8}$$

which is usually chosen as a multiple of the primary PRN code period. In general, *H* can be different from *N* since only a subset of all possible delays can be tested .The two components of Eq. (3.7) represent the real and the imaginary parts of the CAF.

$$Y(\tau,F_D) = Y_I(\,\tau,F_D) + jY_Q(\,\tau,F_D) \tag{3.9}$$

All described features are highlighted in the Fig 3.2. The function of CAF depends upon the Doppler and the delay and both of these factors are evaluated in discrete sets as given in eqs 3.4 and 3.6, CAF results are usually defined on a bi-dimensional grid and is referred as a search space. In search space, each value of Doppler and Delay defines a cell, a variable which is random is to be used for deciding the presence of a signal which is useful. The four functional block are grouped into two parts, first two parts which are the CAF evaluation and Envelop and Average work in cell domain whereas the last two functional blocks which are detection and decision and muti-trial verification operate in decision domain. In order to find out the final acquisition decision, a function of all the search space is used in the decision domain [16].

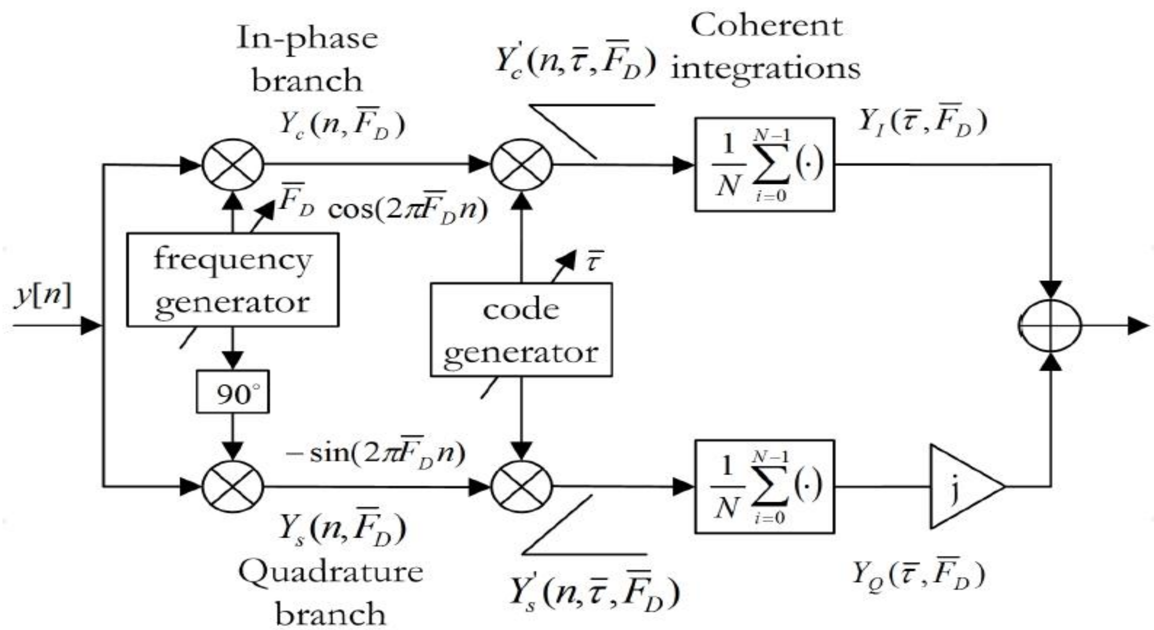


Fig 3.2 Conceptual pattern of Cross Ambiguity Function evaluation. $r(n)$ is the received signal and multiplied by the local replica and orthogonal sinusoids and then the signal is integrated and real and imaginary parts of CAF are generated.

3.3.1 CAF evaluation methods

Different methods of evaluating the CAF is given for acquisition. They give the same or approximately same results depending upon the software and hardware tools used. Different acquisition methods are discussed in subsequent paragraphs.

3.3.1.1 Method 1: Serial scheme

Acquisition of GNSS signal can be taken as 3D search for code shift, frequency offset and visibility of satellites. As Search space is shown in Fig 3.3 ,this serial search acquisition scheme scans all the cell sequentially and stops once the value crosses the certain threshold. In our case where we have set the $\pm$ 14 KHz.acquisition means that there are 29 bins of 500 Hz and PRN sequence length of Beiodu-2 B1 code is 2046 chips. It shows that it will search for 59334 combinations which is very exhaustive search. It is a very simple method and very easy to implement but very time consuming and not an appropriate solution for GNSS software receiver where correlations are carried out in software. The results shows that software of receiver (implemented in Matlab) run on Pentium 4 2.8 Hz is 87 times slower than the FFT acquisition[27,28,29].

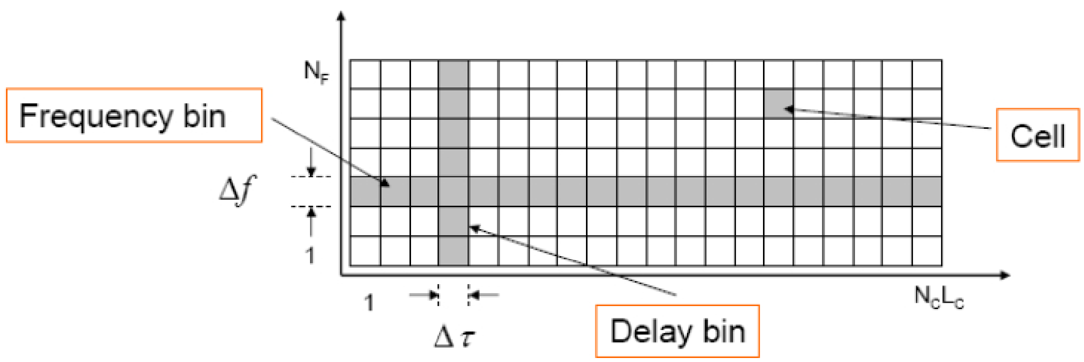


Fig. 3.3 Search Space

Serial search acquisition method is given in fig.3.4, the input signal is multiplied by carrier signal which is locally generated and after that it is divided into I Channel and Q Channel where there is a 90 degree phase shift. After that both I and Q signals are coherently integrated, squared and added. This search will process all carrier frequencies and code delay until a given threshold is crossed[15].

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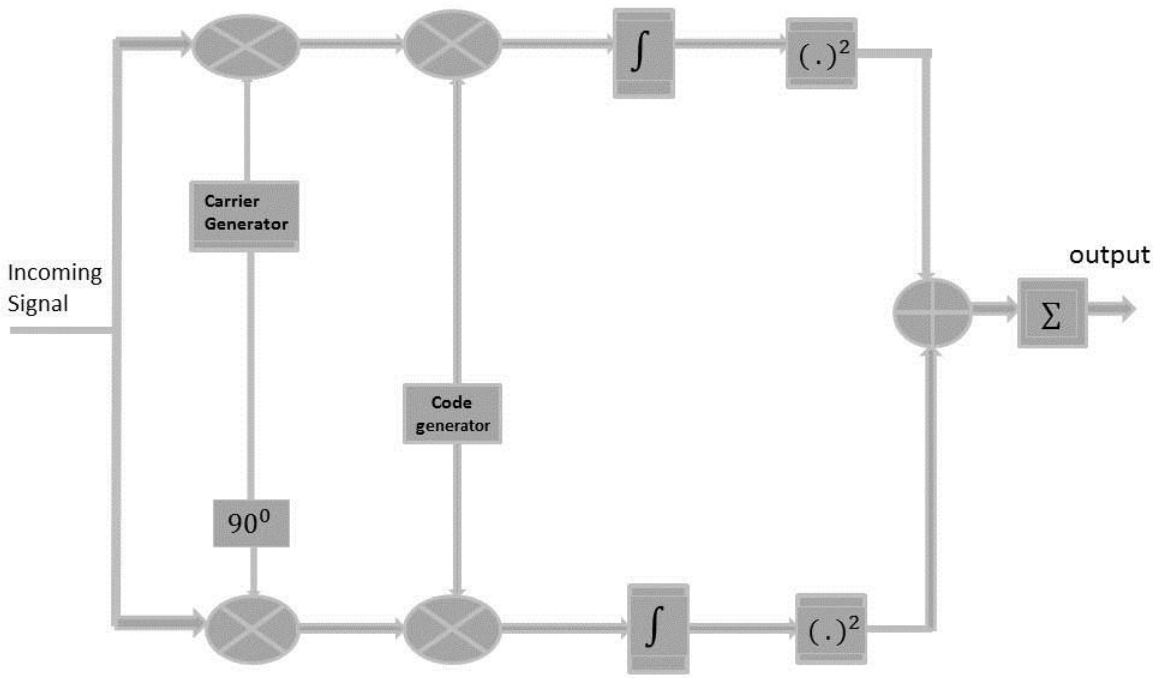


Fig 3.4 Serial Acquisition scheme

Serial acquisition is the most simple method used for evaluation of CAF and at each instant n, a new CAF is evaluated. The $r[n] = [r[0], r[1] \dots . r[N-1]]$ is the input vector and same is updated instant by instant and former value is discarded and new one is added. In order to avoid ambiguity, the notation $r_n = [r[n], r[n-1] \dots . r[n-N+1]]$ is adopted. Using the same approach the τ which is the delay moves at each new instant through out the vector $r_n.c[n]$which is the local code always remain the same and CAF is given by the following equation.

$$Y(\tau, F_D) = \frac{1}{N} \sum_{m=0}^{N-1} r[\tau - N + m + 1]c[m]\exp\{-j2\pi F_D m\} \quad (3.10)$$

Verification of this approach is very easy and equal to the moving of τ of the local code with the mutual delay between the received code and $c[n]$ is the quantity of interest which is unknown[17].

3.3.1.2 Method 2: Parallel Acquisition in the Time Domain

In this method , circular correlation is implemented by carrying out multiplication of incoming signal with the complex conjugate of the B1I local PRN code in frequency domain as shown in fig 3.5 . After that Inverse Fourier transform is taken, a peak will exist at the correct code phase of incoming signal if correct estimation of frequency is carried out. The satellite is acquired if the peak is greater than a certain threshold [15,24,25].

In this method the given sequence for each frequency bin is obtained by extracting the vector r by the SIS incoming and carry out multiplication of the same by $\exp\{-j2\pi F_D\}$,

$$q_l[n] = r[n]\exp\{-j2\pi F_D n\} \quad (3.11)$$

The following term assumes the CCF (Cross-Correlation Function),

$$Y(\tau, F_D) = \frac{1}{N}\sum_{m=0}^{N-1} q_l[n]c[n-\tau] \quad (3.12)$$

and circular cross correlation is used to evaluate the same and is defined by the following expression.

$$\check{Y}(\tau, F_D) = \frac{1}{N}\ IDFT\{\ DFT\big[q_l[n]\big]DFT[c[n]]^*\} \quad (3.13)$$

Whereas DFT stands for Discrete time Fourier Transform and IDFT stands for Inverse Discrete Fourier transform. In case of our algorithm where have set $\pm 14\ KHz$ for frequency search , there will be 29 frequency bins which will be searched and will be much faster than the serial acquisition having 59334 combinations for the same solution.

However this is more faster as compare to the serial search but more complex due to number of FFTs performed[26,27]

If we keep the Sampling frequency of the B1I signal to 2oMHz, there are 20000 points (chips) in one B1I Code period of duration 1 ms. In the acquisition of B1I Signal, The carrier wave for a frequency range of $\pm$14 kHz is generated with a frequency step of 500 Hz. It will have 29 Doppler steps to cover a search space of $\pm$ 14 KHz. FFT on 20000 points with 29 Frequency components will generate 20000 x 29 point outputs[28,29,32**]**.

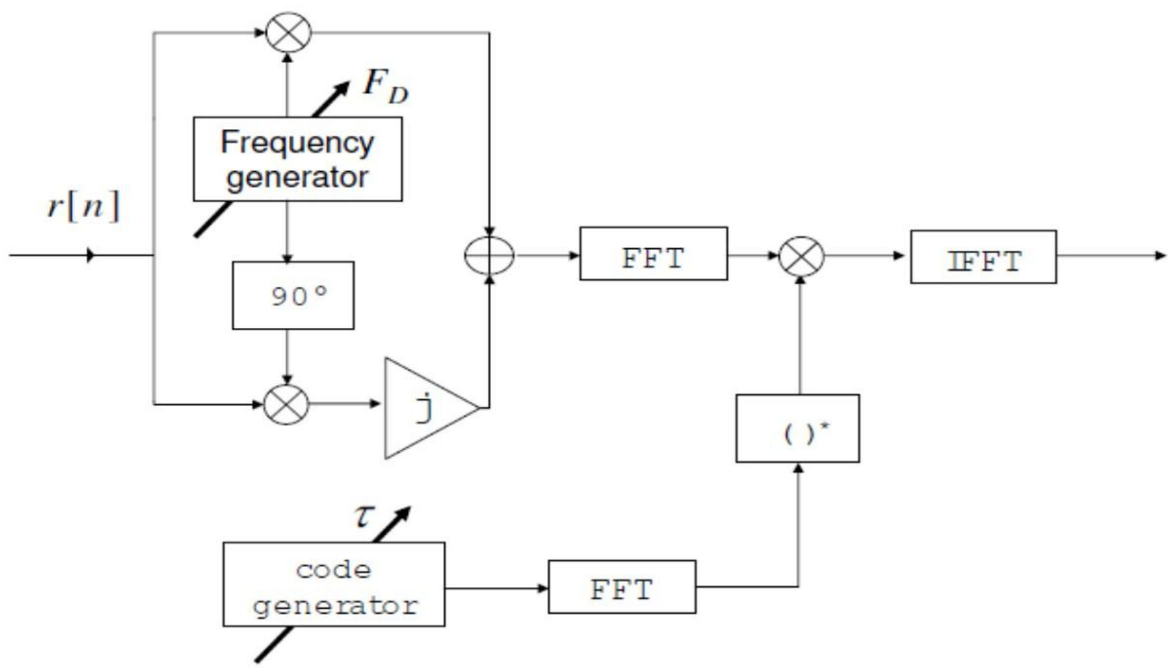


Fig 3.5. Time parallel acquisition method: Using the Circular convolution employing efficient FFT's, the CAF is estimated.

3.3.1.3 Method 3: Parallel Frequency space search

This method parallelizes the search for frequency in which multiplication of incoming signal is carried out with local copy of spreading code and then FFT is implemented for the transformation of the signal into the frequency domain as shown in fig 3.6. Fourier transform will give a significant peak at the correct frequency ,when the correct code phase is selected [15,30].

As explained in the method 1 , instant by instant extraction of vector r is done by the incoming SIS and following sequence is obtained for each delay bin after multiplication by c[n].

$$q_i[m] = r[\tau - N + 1 + m]c[m] \tag{3.14}$$

Same results are obtained when input vector r are extracted from every N samples and delayed version of the local code $c[n]$are multiplied by them. Application of a circular shift to the samples of c[n] cause that delay[16,31]. At this point

$$Y(\tau, F_D) = \frac{1}{N}\sum_{m=0}^{N-1} q_i[m]\exp\{-j2\pi F_D m\} \tag{3.15}$$

The given expression assumes the form of DTFT (Discrete-Time Fourier Transform) . If F_D which is the normalized frequency is discretized with the interval

$$\Delta F = \frac{1}{N} \tag{3.16}$$

of the frequency in the range of (0,1) and is the analogue frequency range ,then the DTFT (Discrete-Time Fourier Transform) can be evaluated. The frequency points which are evaluated becomes

$$f_d T_s = \frac{1}{N} - f_{IF} T_s \tag{3.17}$$

And CAF can be written as

$$S(\tau, F_D) = \frac{1}{N}\sum_{m=0}^{N-1} q_i\,[m]\exp\{-\frac{j2\pi}{N} lm\} \tag{3.18}$$

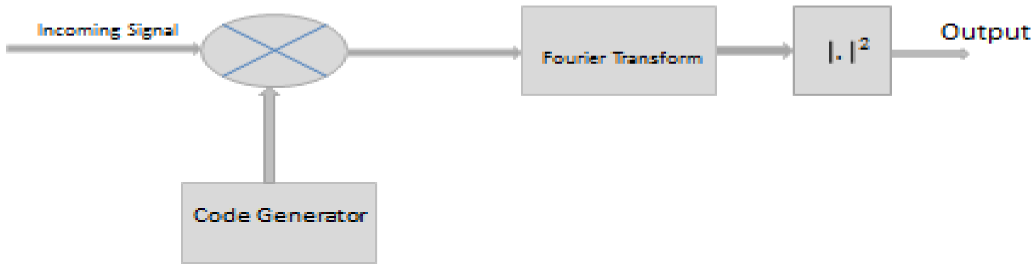


Figure 3.6. Parallel Frequency space search using efficient FFT ,evaluation of CAF is carried out.

3.4 Envelope and Average

Application of noise reduction techniques and removal of the input signal phase dependence has to be carried out after the first stage which was the CAF evaluation. Squaring the absolute value of CAF given in eq 3.1 will remove the dependence on the input signal phase. In this approach search space cell will assume the following term :

$$S(\tau, F_D) = |\frac{1}{N}\sum_{m=0}^{N-1} r[n]c[n-\tau]\exp\{-j2\pi F_D n\}|^2 \quad (3.19)$$

Reduction of noise before the operation of envelop is carried out by the integration block $\frac{1}{N}\sum_{n=0}^{N-1}(.)$.This operation relates to averaging the different CAFs before the evaluation of envelop and is called the coherent integration. In case of noise variance reduction, best performance is given by such integration. the noise terms are zero mean

Gaussian random variables before the envelop . Fig 3.7 shows the basic acquisition scheme which relates to the use of coherent integration only [17].

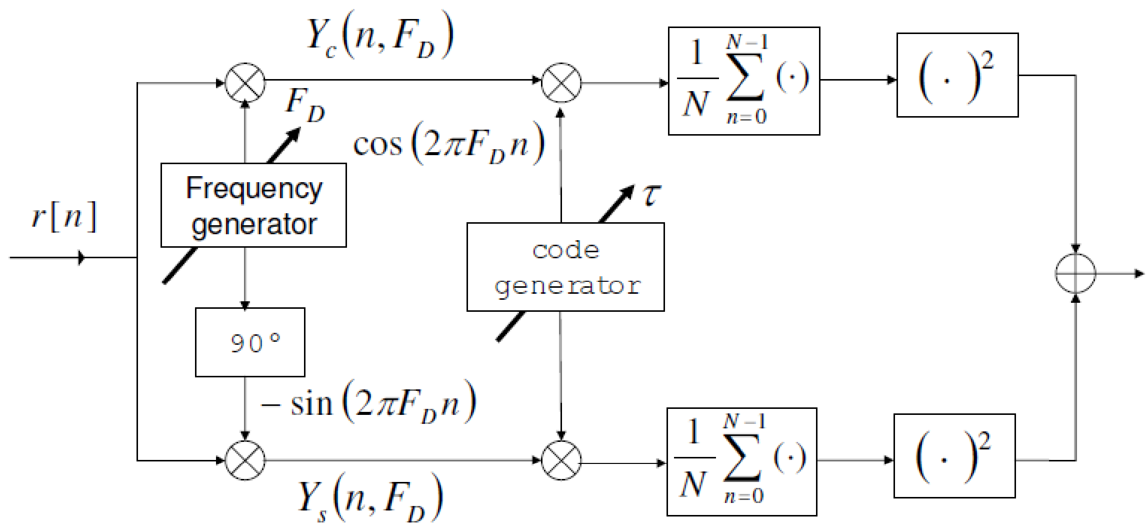


Figure 3.7.Basic Acquisition Block. Coherent integrations are only used.

Envelop is acquired when In-phase and quadrature phase components are squared and summed .In this way $S(\tau, F_D)$assumes the following expression

$$S(\tau, F_D) = Y_I^2(\tau, F_D) + Y_Q^2(\tau, F_D) \quad (3.20)$$

3.5 Detection and Decision

The system can make decision regarding the presence or absence of the satellite once $S(\tau, F_D)$ is evaluated. For this different strategies are applied, in order to explore the search space with the greater accuracy in the acquisition process, three searching strategies are compared and analyzed in subsequent paragraphs.

3.5.1 Maximum Detection strategy

Evaluation of CAF is carried out all over the search space for each value of the code delay and Doppler shift and accordingly decision is taken on the maximum value of the ambiguity function. When the maximum value is greater than the threshold which is imposed, presence of respective satellite system is confirmed and is considered that the satellite is acquired. Furthermore estimated code delay and Doppler shift are those which correspond to the maximum position.[16,17]

3.5.2 Serial Detection strategy

In serial detection strategy, ambiguity function is evaluated serially cell by cell. As soon a value is obtained , it is compared with the threshold and at the first threshold crossing, the process of acquisition is stopped. The estimated code delay and Doppler shift are related to the cell position which is under test. On average, only fifty percent of the search space cell is evaluated by using this approach.

3.5.3 Hybrid Detection strategy

In Hybrid detection strategy , evaluation of the ambiguity function is carried out column by column or row by row and on the maximum of each row or column ,the decision is taken .The acquisition process is over once the maximum in the current row or column exceeds the threshold.

3.6 Multi-trial and Verification

System can refine the results once the first decision of the presence of satellite and first estimation of Doppler frequency and code delay are available. This multi-trial technique is evaluated on the different portions of the input signal and is based on the use of different $S\ (\tau - FD)$.

3.7 Summary

Acquisition is the first step performed by the GNSS receiver and decide about the presence or absence of satellite and give a rough estimate of the Doppler and code delay.

Serial search is exhaustive in terms of computations and require more time for the acquisition whereas the FFT based Acquisition techniques are efficient but complex.

Chapter 4

Interference and Thermal Noise effects on BeiDou-2 GNSS Receiver

4.1 Introduction

In this chapter we will discuss the different classes of interference and noise and its effect on the performance of BeiDou-2 GNSS receiver. Thermal noise of Beidou-2 B1I signal is also calculated in this chapter. we will also cover the different types interferences with respect to the type of sources and factors influencing C/N_0 will also highlighted in this chapter. Noise and interference has significant effects on the acquisition and tracking of GNSS receiver which result into the GNSS receiver performance degradation

4.2 Interference Classification

Addition of more GNNS signal by the growing GNSS community in the same frequency band warrants adding high power which result into the interference and noise. Strength of GNSS signals have extremely low power at earth and due to the same reason they are very much vulnerable to different type of interferences[33,34].

When signal from any source is transmitted of any of the band of GNSS or near to the band of any GNSS, it will cause interference. Major interference in GNSS is intra system interference [35]which is also measured with reference to acquisition performance of Beiodu-2 acquisition and is given in Chapter 6 .There are Different type of interferences and sources which include intentional and unintentional interference.

Several effects of interference and noise may be detected at the output of acquisition block. Interference is classified by different properties and are discussed in detail.

4.2.1 Types of Interference observed in GNSS

a. Continuous wave include all signals which represent pure sinusoids. It is a single tone which represents the vertical line in the amplitude frequency plot[34].

b. The amplitude, phase or frequency of the carrier is changed over time to modulate the PRN code onto a carrier like in case of Beiodu-2 B1I Signal the PRN Code is modulated over the carrier which is 1561.098 MHz and same will spread the BeiDou signal over the major part of the spectrum.

c. Radio frequency random transmissions cause the noise. Spread of amplitude as per the Gaussian distribution is known as Gaussian noise. If in combination with the Gaussian noise, the frequency spectrum is flat is knows as Gaussian white noise.

4.2.2 Centre frequency

In case of Beiodu-2 B1 Signal whose Centre frequency is 1561.098 MHz and has a band of 4.098 MHz, if the interfering signal appears to be within 4.098 MHz it is called in band interference and if it is appeared near to that band ,it is called near band and out of band interference in case of interfering signal outside this band of frequency .

4.2.3. Bandwidth

Interference is also classified as a narrowband and wideband interference as per the interfering signal bandwidth. The differentiating line between wideband and narrow band is not strict as it depends upon the GNSS signal which is considered. However effects of both these types effect the receiver performance.

4.2.4 Power

GNSS signals when reach the earth , they have very low power whereas the interfering signals have high power. The interference power is mostly expressed as signal to interference power or signal to jammer power in decibels depending upon the source of interference.

4.2.5. Time domain

Interference in time domain can either be pulsed or continuous parameters which describe the pulsed interference include the pulse width which is measured in time, duty cycle which is the percentage of time the pulses area transmitted and pulse repetition frequency which is the number of pulses/second. It degrades the GNSS receiver performance.

4.3 Interference sources

Interference sources are also characterized by mean of sources which area intentional and unintentional sources.

4.3.1 Intentional source

GNSS are basically designed as military system and so should take account of intentional interference which is basically the jamming from hostile equipment. Even system which are primarily used as civilian system like Galileo also cater for intentional interference in order to avoid any terrorist activity especially in case of applications like safety of life.

4.3.2 Unintentional interference

In a peaceful environment, most of the interference which is observed is unintentional interference which is due to the natural interferences or by use of same frequency band[36]. In Table-4.1 [1] list of unintentional interferer is given which all are expected in GNSS band.

Unintentional interferers	**Frequencies (MHz)**	**Description**
Pseudolites	frequencies of all GNSS	Pseudlites are the Ground based transmitters which are used for navigation signal and their signal structure is also similar to the GNSS signals. As the distance between the transmitter and receiver is not much so these signal have good power as compare to the GNSS signals which are very weak at earth.
All GNSS	frequencies of all GNSS	In case of intra system interference, GNSS interfere with themselves and incase of inter system interference they interfere with other systems. Several

		studies shows that such kind of interference is not detectable in field environments [38].
TACAN	960-1164	TACAN is the tactical air navigation system which is mainly used by non-commercial aircraft. This system make use of DME and have pulsed signals, it also gives the bearing information
DME	960-1164	DME is the distance navigation equipment which is placed at airfields and used for the navigation of aircrafts. The signals of DME are pulsed and its bandwidth depends upon the air traffic make use of it..
ADS	960-1164	Automatic dependent surveillance is used for the surveillance of aircrafts and gives the information to the aircraft aggrading the position and altitude of other aircrafts.
Link 16	960-1164	Link 16 use pulsed signals and is a military communication
RADAR	960-1164 1215-1240	These are the frequencies which are mainly used by Radars

Amateur radio	1240-1300	This band has been given Amateur radio by ITU as long as this radios does not cause interference to other services.
Cellular Communication		1350-1400
Satellite communications Systems	1535-1559	Downlink(space-earth)
Mobile Satellite Systems	1610-1660.5	(uplink) earth-space mobile satellite system link.

Table. 4.1 Unintentional interferers

4.4 The effects of interference on GNSS receiver output

Interference has adverse effects of the performance of receiver and some of these effects are given as under:

a. Degradation of acquisition performance

b. Receiver tracking loss

c. Decrease of measured CNR

d. Increase of cycle slips in the phase measurements

e. Increase of noise on the measurements of pseudo range

f. Increase of noise on the measurements of phase

4.5 Thermal Noise on phase measurements

Third derivative of the phase measurement is taken to determine thermal noise similar to the noise on pseudo range measurements [40]. However following are the complicating factors:

a. Thermal noise on phase measurements and clock noise of the GNSS receiver have same order of magnitude. Therefore clock noise and the thermal noise will not be by differentiated by taking the third derivative. In order to separate the clock noise from thermal noise, the fact that clock noise will be same for all visible or tracked satellites and carrier frequencies can be used. Number of carriers are tracked , we take the mean noise of all carriers at some epoch and same will be close to the clock noise at that epoch. By calculating the mean value at each epoch we can determine the clock noise and same can be differentiated by the thermal noise.

b. Cycle slips van be a indication of interference on the GNSS signals and can also be present in the phase measurements. Detection of cycle slips can be determined by the observing the sudden increase of phase measurements. In order to determine the phase noise , these cycle slips are removed once they are detected.

4.6 Calculation of Thermal Noise on Beiodu-2 B1 Signal

Thermal noise is defined by the given equation[40]:

$\boldsymbol{P_{ThermalNoise}} = \boldsymbol{kTB}$ Where,

k- botlzmann's constant = 1.38 x 10^{-23}J/K

T-Absolute temperature in K

B-Equivalent noise bandwidth in Hz (Bandwidth of BeiDou-2 B1I Signal is 4.098MHz)

Thermal noise for Beidou-2 B1I Signal:

(1.38 x 10^{-23})(290)(4.098 x 10^{6})= 10x LOG_{10}1.64 x 10^{-14}

Thermal noise of Beiodu-2 B1I signal in dB:

-137 dBW.

4.7 Factors influencing the C/N_0

Noise on the phase and pseudo range measurements or cyclic-slips on the measurement of phase effects the Acquisition of 3D search, tracking of satellite and accuracy in determining the position , velocity and time. Increase of carrier to noise ratio will improve the acquisition performance and same has been proved in Chapter 6 by plotting the graph of CNR verses Acquisition Performance metric. Carrier to noise ratios determines the power of the signal with reference to noise and perform the receiver performance[41]. Factor influence the C/N_0 are given in the Table 4.2

Factors	**Measurements**	**Description**
Variations in GNSS Satellite power	6dB	Approximately 6 dB more power is transmitted by the new Satellites and same is decreased with the life of satellite.
Variations in the free-space propagation loss	2dB	Free space loss depends upon the distance between the transmitter and receiver. When there is a decrease of the elevation angle of the satellite, the distance to receiver is also increased and accordingly propagation loss is also increased.

Varying satellite antenna gain with nadir angle	3dB	The GNSS satellites transmitting antennas are so designed that they cancel out the effect of increasing propagation loss due to the decrease of the elevation angle
Variations in atmospheric losses	2dB	estimation of atmospheric losses is difficult but normally they are within 2db.
Foliage attenuation	N/A	Leaves of tree falling in line of sight effects the received power , however selecting the site for receiver may overcome this problem.
Multi-path	N/A	line of sight signal and reflected signal have the phase difference, received power can be decreased or increased by the multi-path.
Varying receiving antenna gain with satellite elevation	15dB	Antennas of GNSS can have gain roll-off upto 15 dB From zenith to the horizontal

Table 4.2. Factors influencing C/N_0

4.8 Summary

Noise and interference has significant effects on the acquisition and tracking of GNSS receiver which result into the GNSS receiver performance degradation. In peace time, the most common sources of interference are unintentional and out of these intra system interference is the major source observed in GNSS . Effect of Intra system interference and carrier to noise ratio on Acquisition of Beiodu-2 B1 Signal is covered in Chapter 6.

Chapter 5

Simulation and Acquisition of BeiDou-2 B1I Signal

5.1 Introduction

In this chapter, the acquisition of BeiDou software receiver is implemented by evaluation of Cross Ambiguity Function (CAF) by FFT based Coherent Parallel Code phase Search scheme in the presence of Interference, Doppler and thermal noise. B1I Gold Code Generator is also implemented in this chapter along with BeiDou-2 B1I GNSS signal for algorithm development and testing.

5.2 BeiDou-2 Receiver Architecture

RF section and IF section are two major parts of the BeiDou-2 GNSS receiver as given in fig 4.1. The RF section covers the hardware modules which are analogue and responsible for conversion from RF to IF, While IF modules are digital modules. The second part is the base band processing of the signal which include the acquisition, tracking and computation of Position Velocity and Time[42]

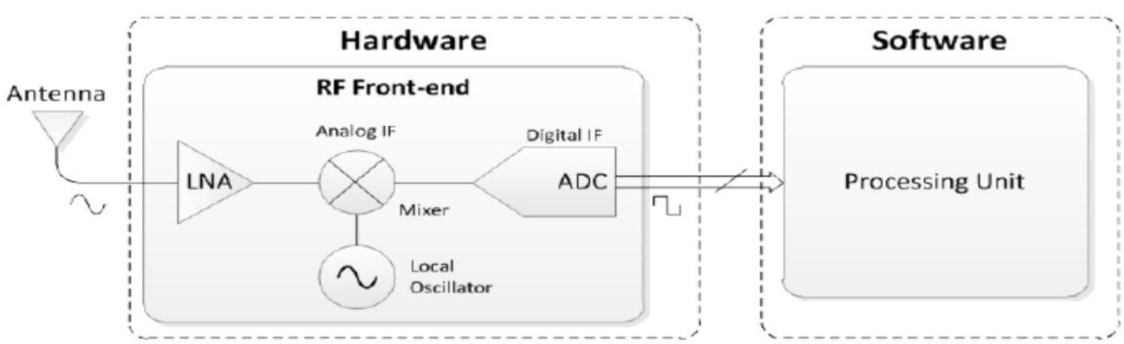


Fig 5.1 Architecture of BeiDou-2 Receiver

The process start when signalBeiDou-2BI1 signal at carrier frequency 1561.098 MHz is transmitted from the satellite , propagating through the space and incident on the receiver. There are filtering and low noise amplification stages after the antenna as the received signal is having the low power. Then processing of the RF signal is carried out at the RF frontend . After the amplification of a signal from the antenna , the receiver is down converting the input signal from RF to low IF. Down conversion is carried out by mixing the incoming signal with the local oscillator (LO) and same is followed by band pass filtering. After the mixing , the PRN codes and Doppler are preserved and only carrier frequency is lowered.

The resulting IF is converted to digital IF signal through the analog to digital converter. The ADC sampling frequency to be carefully selected as per the Nyquist frequency to avoid aliasing. The signal is then forward to the processing unit which will carry out necessary baseband computations.

The data for processing the acquisition part is collected from the Ohio University research and organization site [43]and from the DVB-T device which is configured as RF Frontend[44]. Collection of simulated data is also carried out from the BeiDou-2 GNSS signal Generator. The flow diagram of BeiDou-2 software receiver shows the three blocks required for computation of PVT which includes the Acquisition, Tracking and position solution. The focus of this work is till acquisition of B1I signal and accordingly carry out the performance verification of the Acquisition algorithm with the BeiDou-2 GNSS simulator in the presence of Doppler , interference and thermal noise[45].

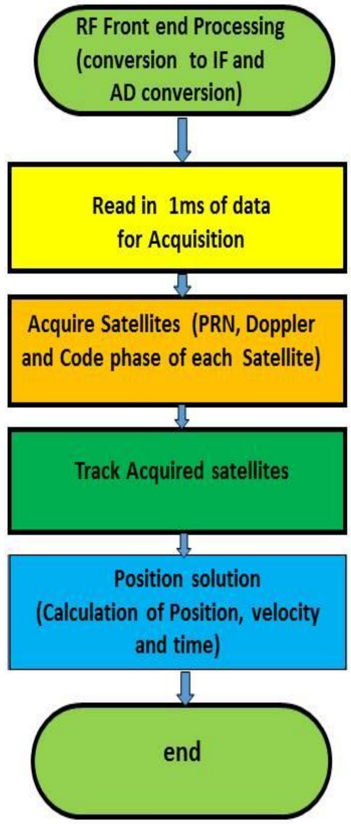


Fig 5.2 BeiDou-2 software Receiver flow diagram

5.3 RF Frontend

The DVB-T device along with active antenna is configured as a front end which provides the digital samples ofBeiDou-2 to the host computer for the BeiDou-2 Software Receiver implementation[44]as shown in the Fig 5.3

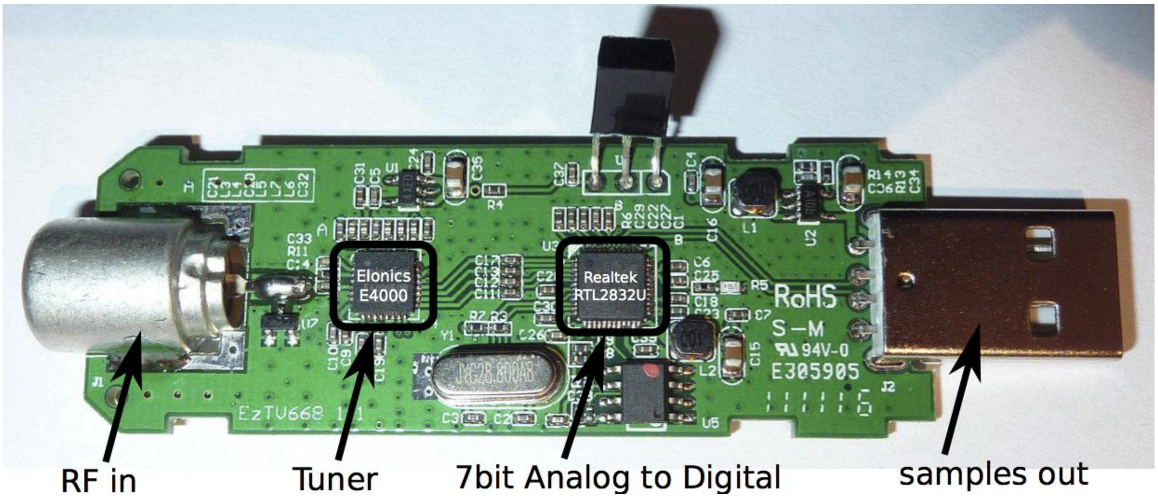
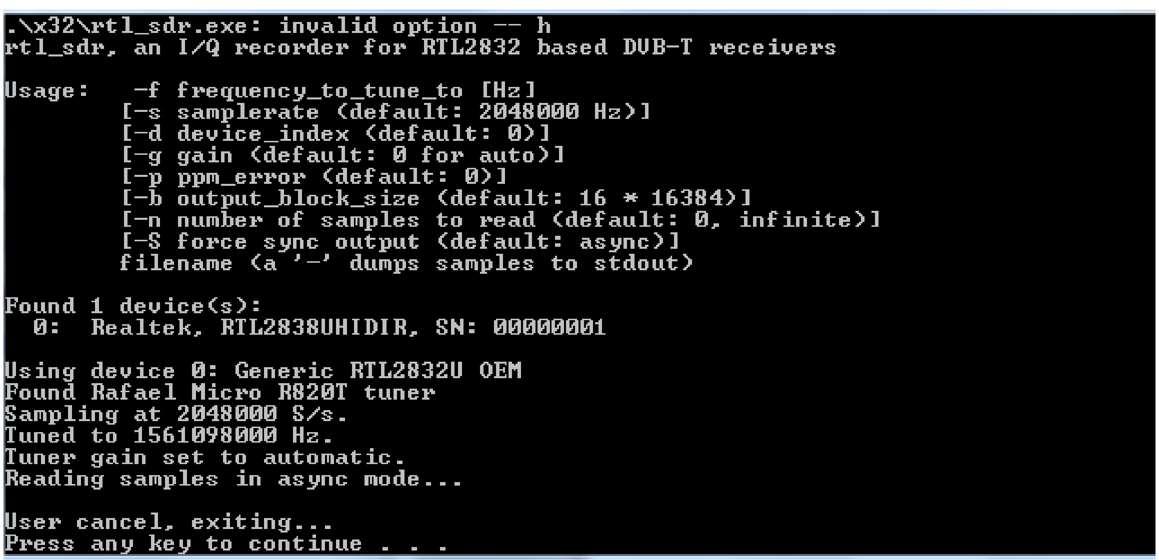


Fig 5.3 DVB-T device configured as RF Frontend

Active antenna is used with the device which receives the Beiodu 2 B1I signal and device is tuned up on 1561.098 MHz frequency and after analog to digital conversion the samples are forwarded to Acquisition block for baseband processing. Settings of RF Front end are given in Fig 5.4.



```
.\x32\rtl_sdr.exe: invalid option -- h
rtl_sdr, an I/Q recorder for RTL2832 based DVB-T receivers

Usage:    -f frequency_to_tune_to [Hz]
         [-s samplerate (default: 2048000 Hz)]
         [-d device_index (default: 0)]
         [-g gain (default: 0 for auto)]
         [-p ppm_error (default: 0)]
         [-b output_block_size (default: 16 * 16384)]
         [-n number of samples to read (default: 0, infinite)]
         [-S force sync output (default: async)]
         filename (a '-' dumps samples to stdout)

Found 1 device(s):
  0:  Realtek, RTL2838UHIDIR, SN: 00000001

Using device 0: Generic RTL2832U OEM
Found Rafael Micro R820T tuner
Sampling at 2048000 S/s.
Tuned to 1561098000 Hz.
Tuner gain set to automatic.
Reading samples in async mode...

User cancel, exiting...
Press any key to continue . . .
```

Fig 5.4 DVB-T device tuned up on Beiodu-2

5.4 FFT based Coherent Parallel Code Phase Search Acquisition

Data has been acquired through [43]and through Front end and after that a chunk of 1ms of a data is taken for the acquisition . The acquisition of the B1I signal is carried out by using a Coherent Parallel Code phase Search which is making use of Fast Fourier transform for transformation from time domain to frequency domain as given in Fig 5.5.

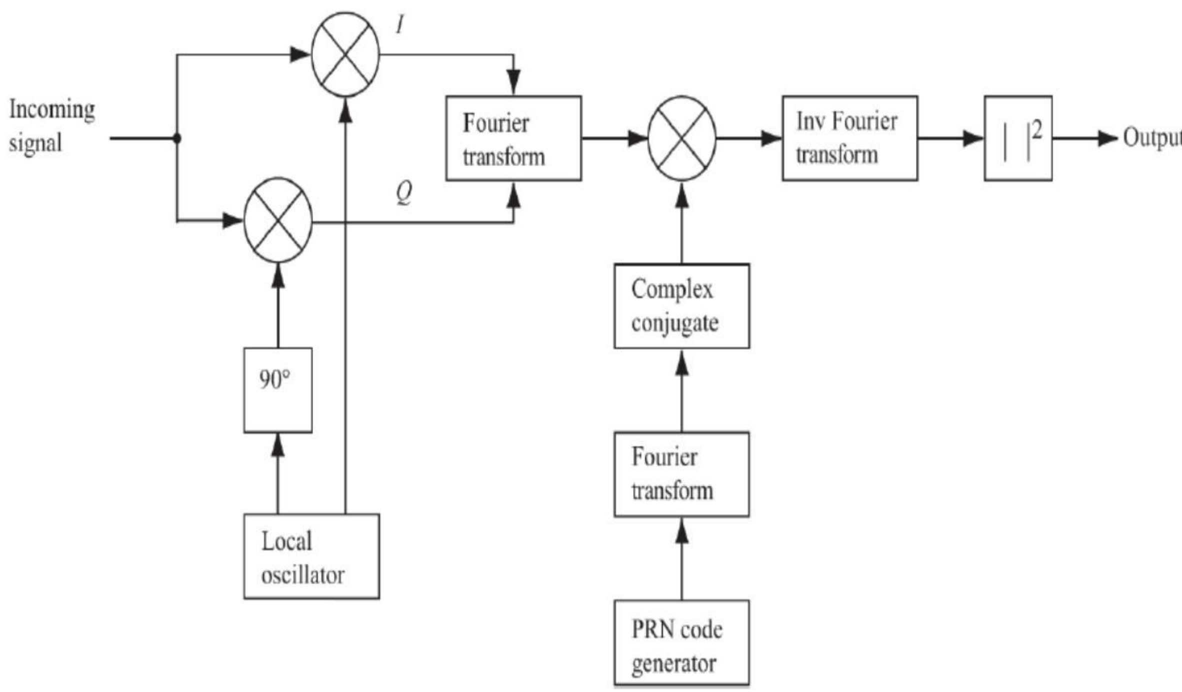


Fig 5.5 . Block Diagram of Coherent parallel search acquisition

Primarily the incoming signal of BeiDou-2 is multiplied by the generated cosine and sine wave and obtaining the In-phase (I) and Quadrature (Q) signal. As a complex input, these two signals are combined to the Fourier transform. With zero code phase ,PRN code is generated and then Fast Fourier transform is applied and the result is complex conjugated. The PRN code generator with the size of 2046 Chips and rate of 2.046 MCs of BeiDou-2 system is covered in the next section. The complex conjugate of

PRN code with zero phase is multiplied with the Fast Fourier transform of the incoming BeiDou signal and then Inverse Fast Fourier transform of the result is taken. The output will show the distinct peak in magnitude and is given in fig 5.6(a). Maximum of the correlation amplitude, will be compared to the threshold and if threshold is crossed then acquisition ends and the Doppler estimation and code phase are identified along with PRN number of the satellite. Number of computations which are required to form correlation are significantly reduced through FFT based Acquisition. Fig 5.6 (b) shows that there is no correlation and hence no acquisition of satellite.

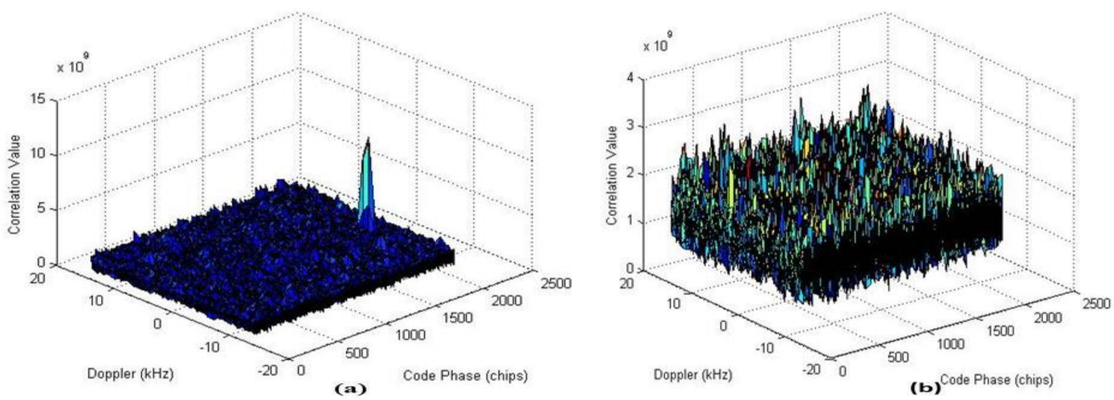


Fig 5.6 (a) Acquisition of BeiDou-2 Sat with respective Doppler and Code Phase **(b)** No Acquisition

Visibility of different satellites of BeiDou-2 once acquired is given in Fig 5.8 which shows the visibility of Beidou-2 satellites number 2,3,5,7 and 10.

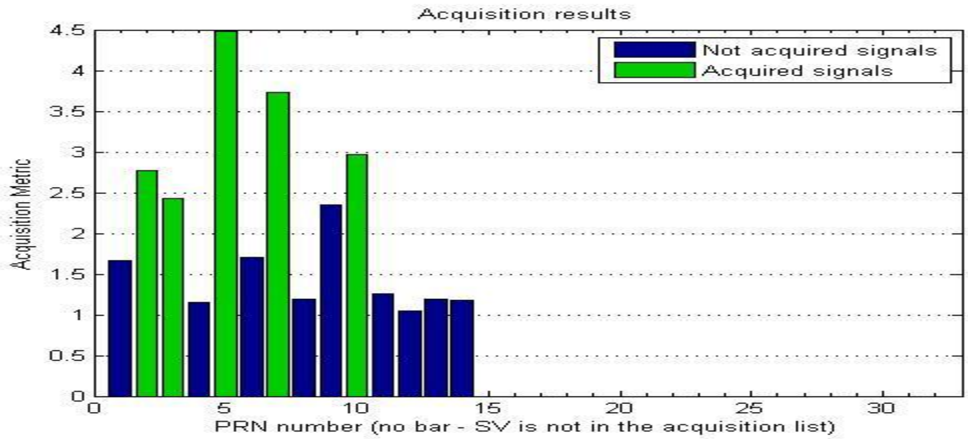


Fig 5.7. Acquisition of Beiodu-2 satellites

The signals are further processed for Tracking. Flow diagram of our Acquisition algorithm as given in Fig 5.9.

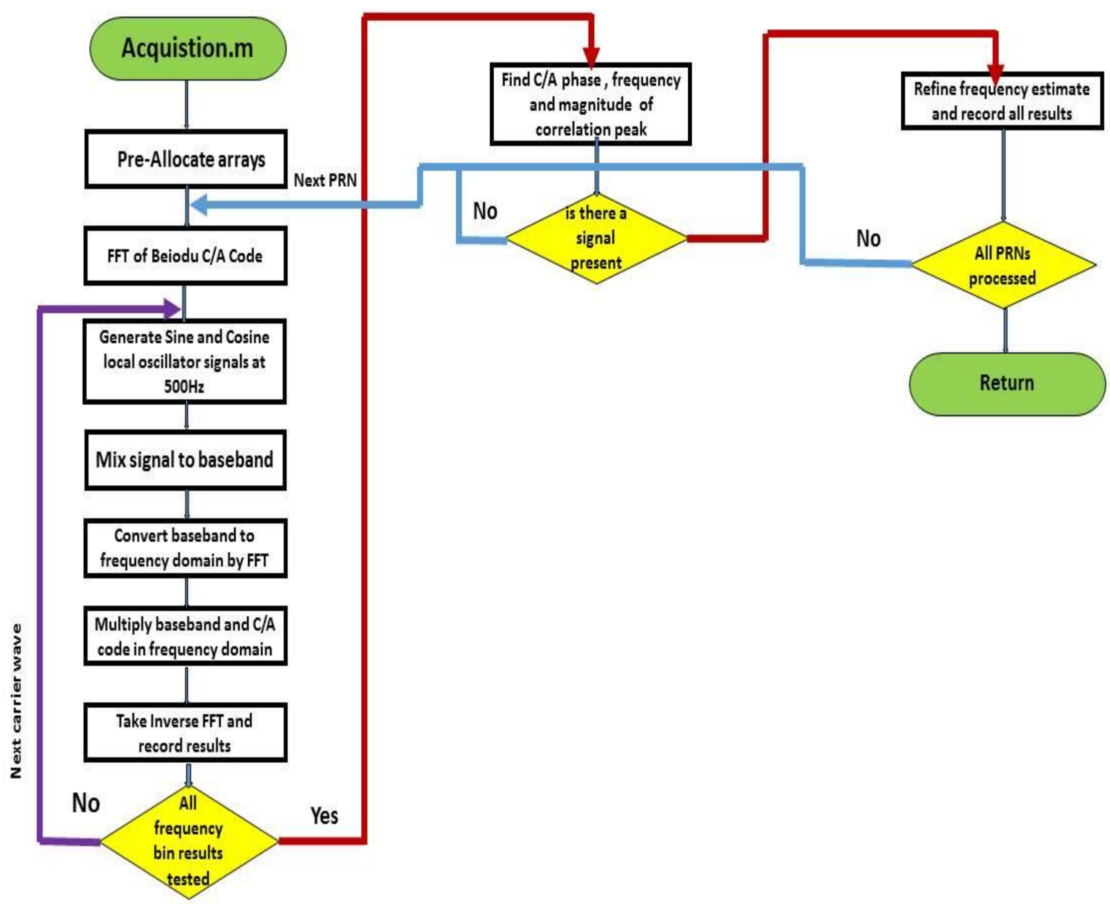


Fig 5.8 Flow diagram of the parallel acquisition of B1I signal of BeiDou-2

5.5 Beiodu-2 B1I Gold Code Generator

BeiDou-2 is a DS-CDMA system and in order to ensure that each satellite transmit a different code ,Gold Code Generators are being used. B1I signal has the chip rate of 2.046 Mcps with the sequence length of 2046[46] .Block Diagram is given in the Fig5.10.

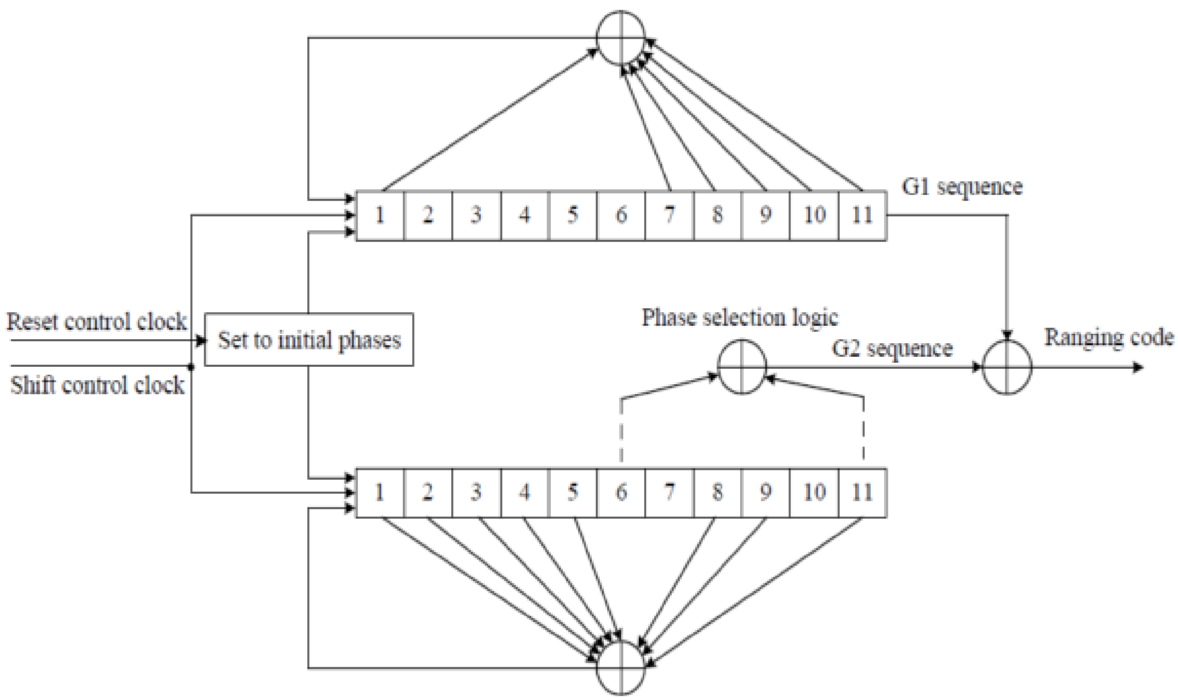


Fig 5.9 Gold Code Generator.

The Gold Code of B1I has two sequences G1 and G2 which are used to generate Gold code and works on modulo 2 addition at the output [21]. The generators G1 and G2 are derived from 11-bit linear shift register .The G1 and G2 polynomials are given as:

G1(X)=1+X+X7+X8+X9+X10+X11

G2(X)=1+X+X2+X3+X4+X5+X8+X9+X11

The initial phases of Generator 1 and 2 are as under :

G1: 01010101010,G2: 01010101010

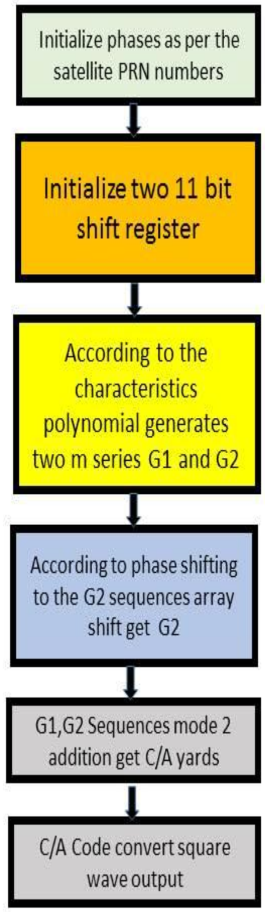


Fig 5.10 The flow chart of Beiodu-2 B1I code generation

Taps employed at the G2 output are 1,3; 1,4; 1,5; 1,6; 1,8; 1,9; 1,10; 1,11; 2,7; 3,4; 3,5; 3,6; 3,8 ,3,9; 3,10; 3,11;4,5;4,6; 4,8; 4,9; 4,10; 4,11; 5,6; 5,8;5,9; 5,10; 5,11; 6,8; 6,9; 6,10; 6,11; 8,9; 8,10; 8,11; 9,10; 9,11 and 10,11. These taps are showing the selection of different states for the code and generates the different C/A code for BeiDou-2 satellites. Same PRN generator is employed at the Satellite transponder for differentiating the BeiDou-2 signals from the other constellation and same is used at the Acquisition Block of the Beiodu-2 Receiver for carrying out the correlation of the signal[8] .Flow chart of the C/A code generation is given in Fig 5.10

5.6 BeiDou-2 GNSS Simulator

BeiDou GNSS simulator is also implemented using Matlab in this Thesis, so performance based verification of our Acquisition algorithm is carried out. In this Simulator we have full control over the signal power levels, Doppler shifts and generation of the noise. By simulating the BeiDou signal , we can introduce each of these impairments in a scenario-specific combinations and individually to improve the design and to address the trouble shooting[47,48]. Block diagram of BeiDou-2 GNSS simulator is given in Fig 5.11

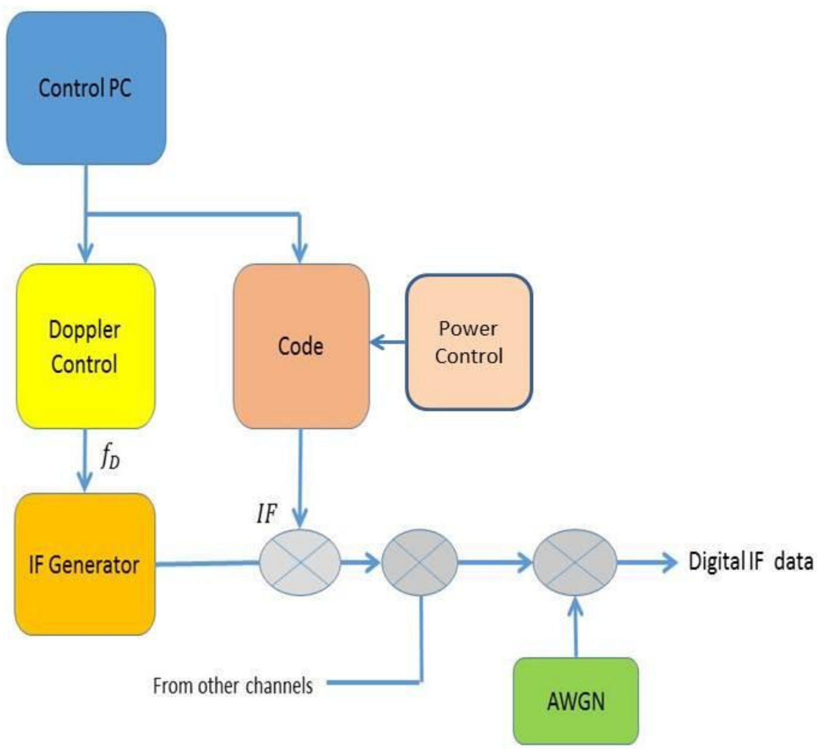


Fig 5.11. Block diagram of Beiodu-2 GNSS Simulator

5.6.1 BeiDou-2 Satellite Power levels

The designed BeiDou signal simulator gives us the ability to adjust the power levels of 14 simulated BeiDou Satellites and same can be increased upto 37 satellites. More realistic reproduction of the environment is offered by varying the power levels of different satellites .With the addition of AWGN and varying the power level of signal, the performance of the BeiDou receiver can be measured, which is Carrier to noise ratio verses the acquisition performance. By increasing the power level of the neighboring satellites, the carrier to interference ratio verses acquisition metric of the signal can also be verified

5.6.2 Simulation of BeiDou-2 signal with Doppler Shift

BeiDou-2 satellites orbit about 20200 km and the resulting orbital period is almost 12 hours with an orbital velocity of 3900 m/s. That will cause the Doppler shift (the satellite motion alone) in the single satellite. When same is combined with the subtle Doppler shift from the mobile receiver and the rotation of earth , the BeiDou receiver takes a new shape and receiver is required to be tested under such environment. With the help of this designed simulator, the performance of algorithm can be measured by varying the Doppler shift in BeiDou signal and reading its effects on acquisition performance.

5.7 Summary

Beiodu-2 B1I Simulator with the effect of adjusting power levels of different satellites , addition of AWGN and introducing Doppler effect is implemented .Acquisition of Beiodu-2 B1 signal using FFT based Coherent Parallel Acquisition Code phase search is also implemented. Simulations and results on simulated and actual data of Beiodu-2 B1I signal is given in the Chapter 6.

Chapter 6

Simulations and Experimental Results

6.1 Introduction

In this chapter Beiodu-2 GNSS signal Acquisition and simulation of B1I signal is carried out and correlater output is taken as the decision variable. Acquisition of Beiodu-2 B1I signal is carried out on the actual data of BeiDou and on the simulated data. Different scenarios have been presented and Monte Carlo simulations have also been carried out for the performance measurement of the algorithm. Sky plots[49] have also been used to validate the acquisition results.

6.2 Acquisition of Simulated data

Acquisition of BeiDou-2 simulated data is carried out and PRN numbers have been acquired as shown in Fig 6.1.

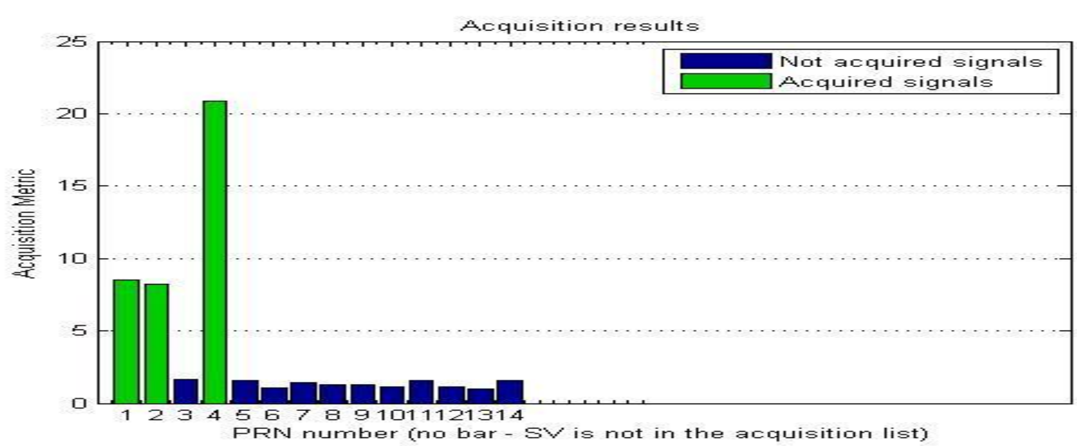


Fig 6.1 Acquisition of Simulated data showing the Visibility of satellite number 1,2 and 4

In simulation the algorithm can be tested under different conditions. This simulation is carried out in the presence of AWGN with no Doppler and interference problem. Fig 6.2 shows the Acquisition of Beiodu-2 Satellites with the estimated Doppler and code delay.

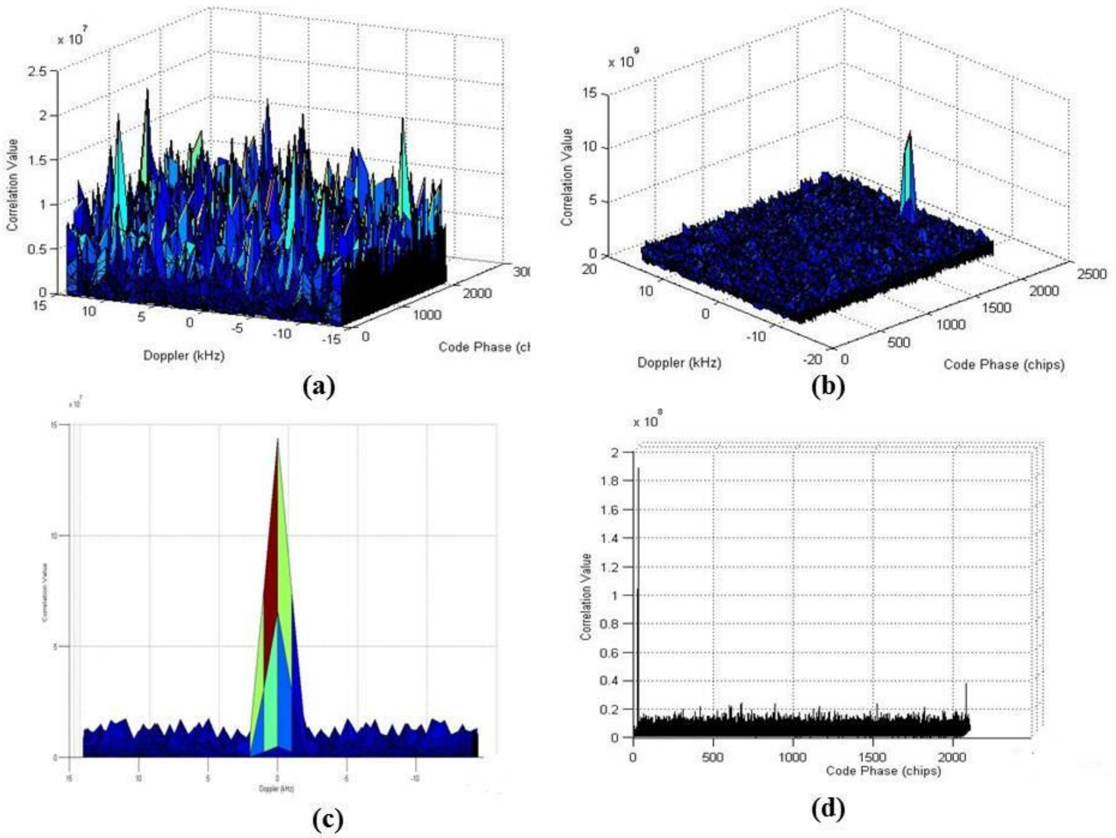


Fig 6.2 Correlation of Acquired satellite with the estimated code delay and Doppler **(a)** No Acquisition **(b)** Acquisition showing presence of Sat**(c)** Doppler of received Sat **(d)** Code phase of Sat

6.3 Acquisition of BeiDou-2 Data Collected at Islamabad, Pakistan

Using RF Frontend Beiodu-2 ,data has been collected at Islamabad, Pakistan and accordingly acquisition has been carried out. The sky plot[49] of Islamabad is shown in the Fig 6.3 and Acquisition results of our Receiver are given in Fig 6.4.

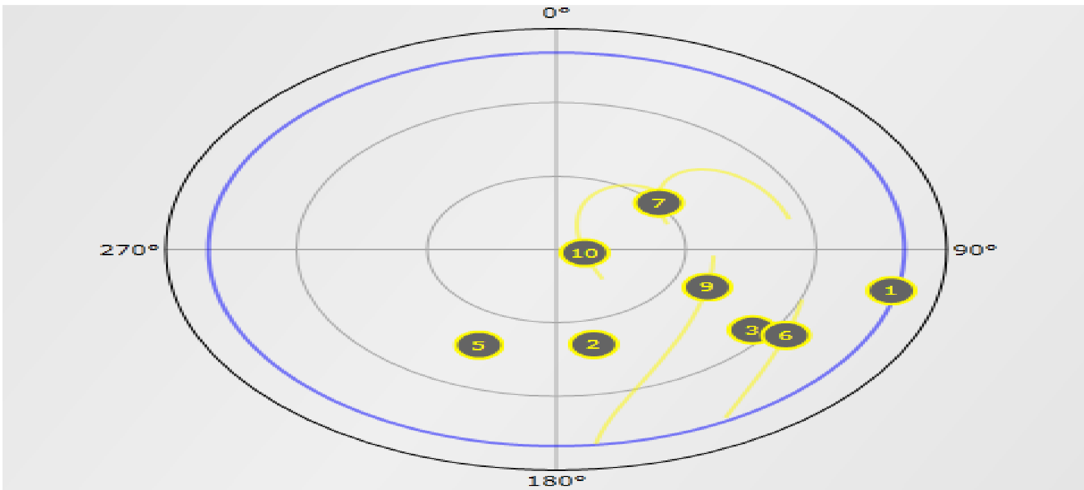


Fig 6.3 Sky-plot of BeiDou-2 satellite navigation system was taken at (UTC+5)5:50 PM at Islamabad on 7 December 2014with an elevation cut-off angle of 10 degree.

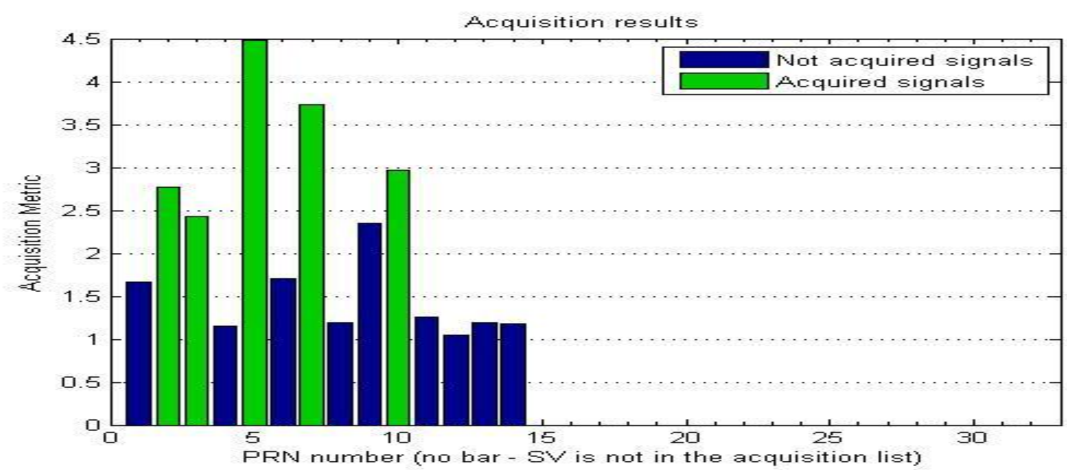


Fig 6.4 Acquisition of Beiodu-2 B1I Signal of sat 2,3,5,7 and 10.

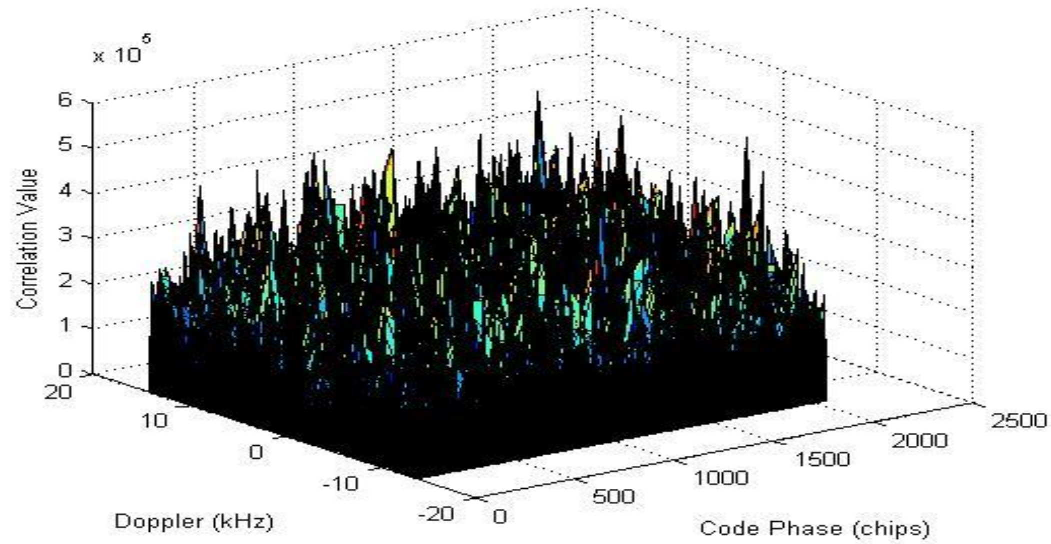


Fig 6.5 No Acquisition.

Which shows that signals of Beiodu-2 satellite numbers 2,3,5,,7,10 have been acquired. The BeiDou-2 satellite tracks[49]over Islamabad, Pakistan are given in Figure 6.6.and Acquisition of satellite number 2,3,4,7,and 10 have been shown from fig 6.7 to 6.11 along with estimated Doppler and Code delay.

Fig 6.6. Tracks of BeiDou satellite navigation system at (UTC+5) time 5:50 PM over Islamabad on 7 December 2014 with an elevation cut-off angle of 10 degree.

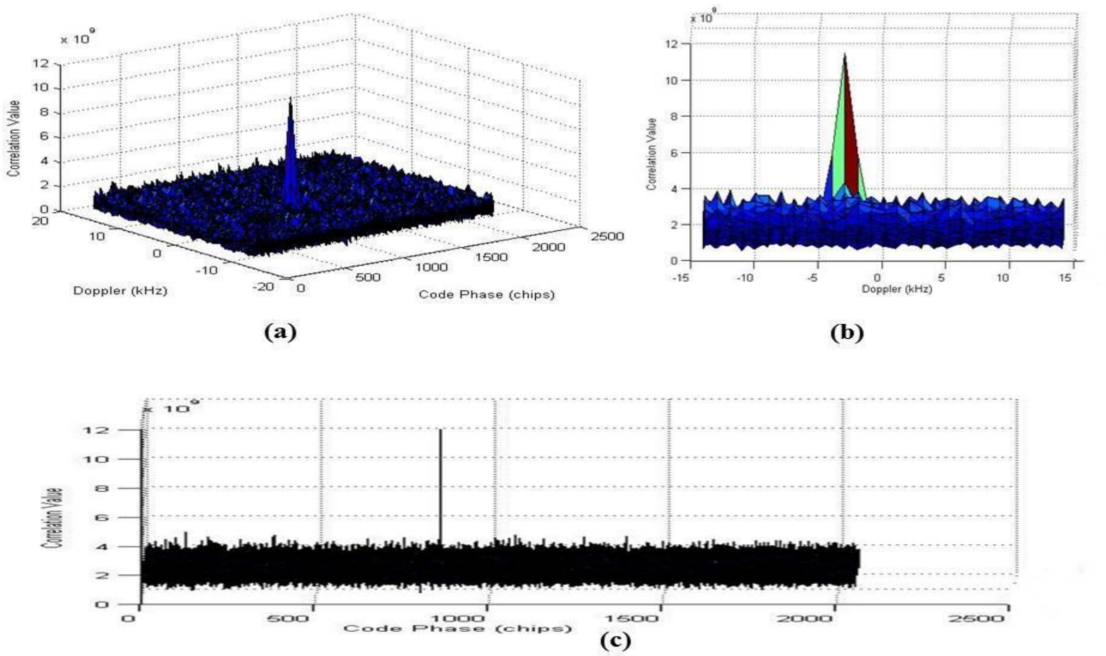


Fig 6.7 Correlation of satellite with the estimated code delay and Doppler

(a) Acquisition of Sat-2 **(b)** Doppler of Sat-2 **(c)** Code phase of Sat-2

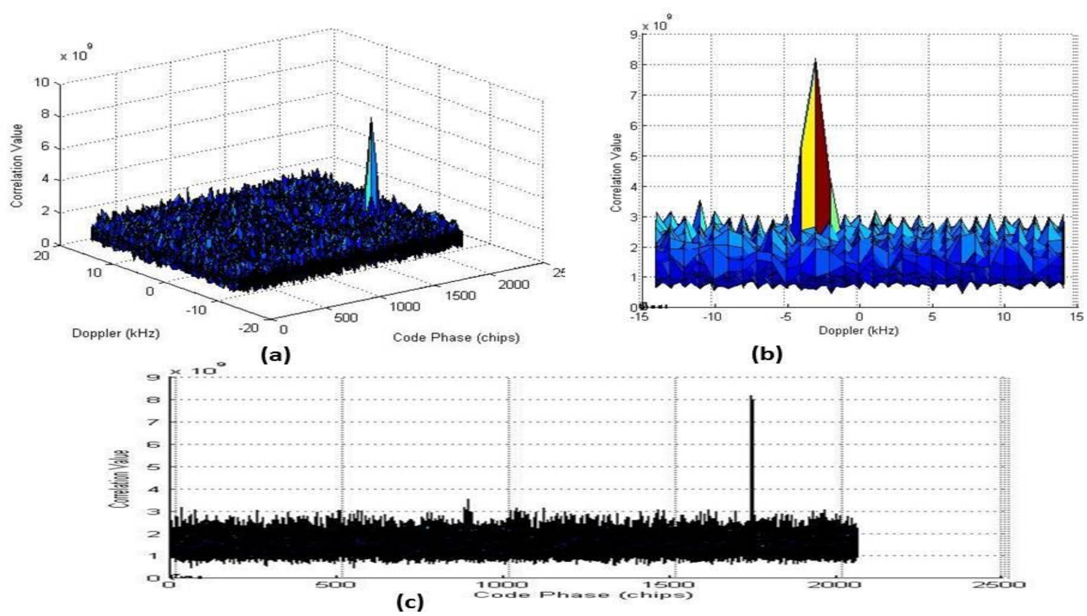


Fig.6.8 Correlation of satellite with the estimated code delay and Doppler

(a) Acquisition of Sat-3 **(b)** Doppler of Sat-3 **(c)** Code phase of Sat-3

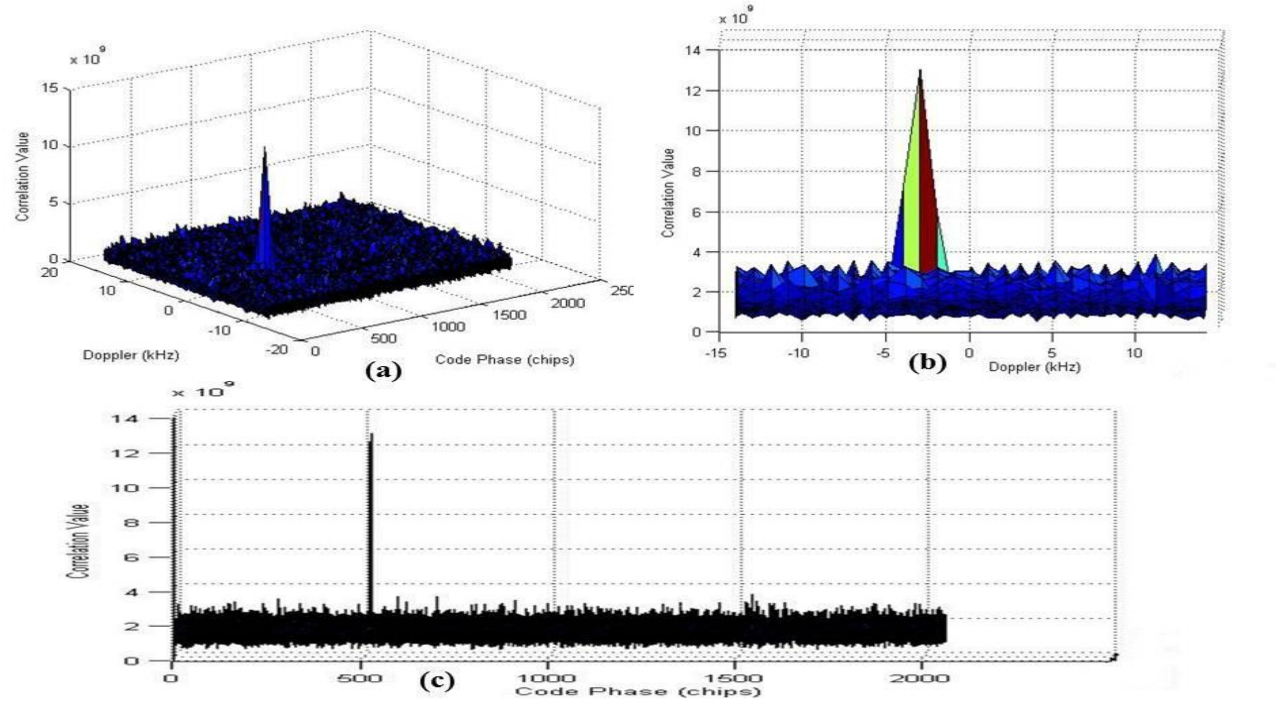


Fig 6.9 Correlation of satellite with the estimated code delay and Doppler

(a) Acquisition of Sat-5 **(b)** Doppler of sat-5 **(c)** Code phase of Sat-5

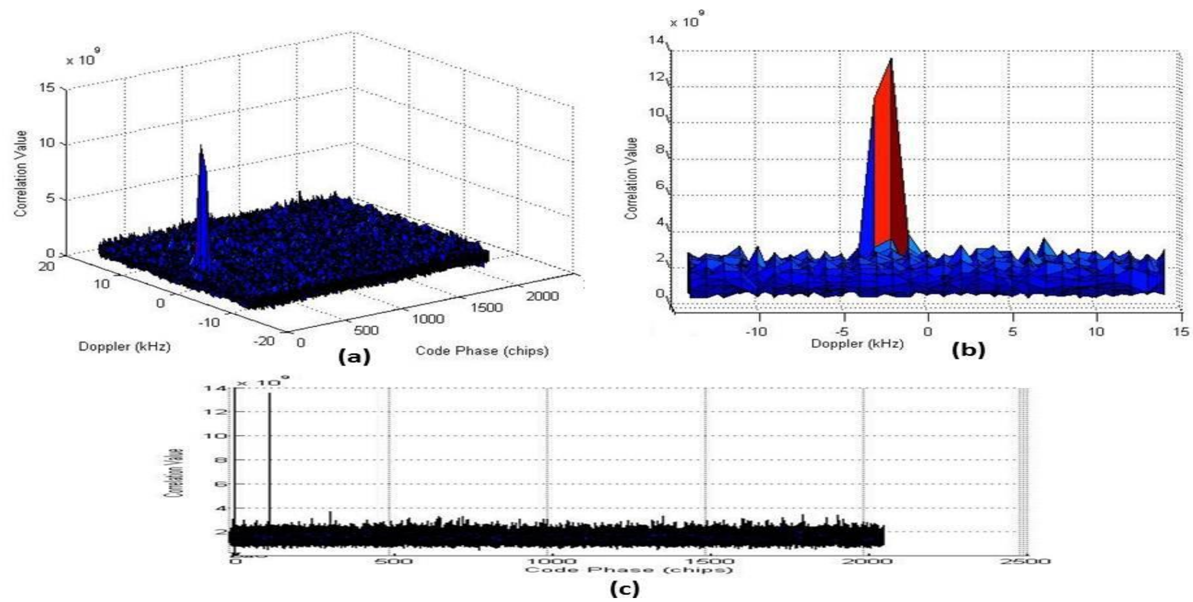


Fig. 6.10 Correlation of Acquired satellite with the estimated code delay and Doppler**(a)** Acquisition of Sat-7 **(b)** Doppler of sat-7**(c)** Code phase of Sat-7

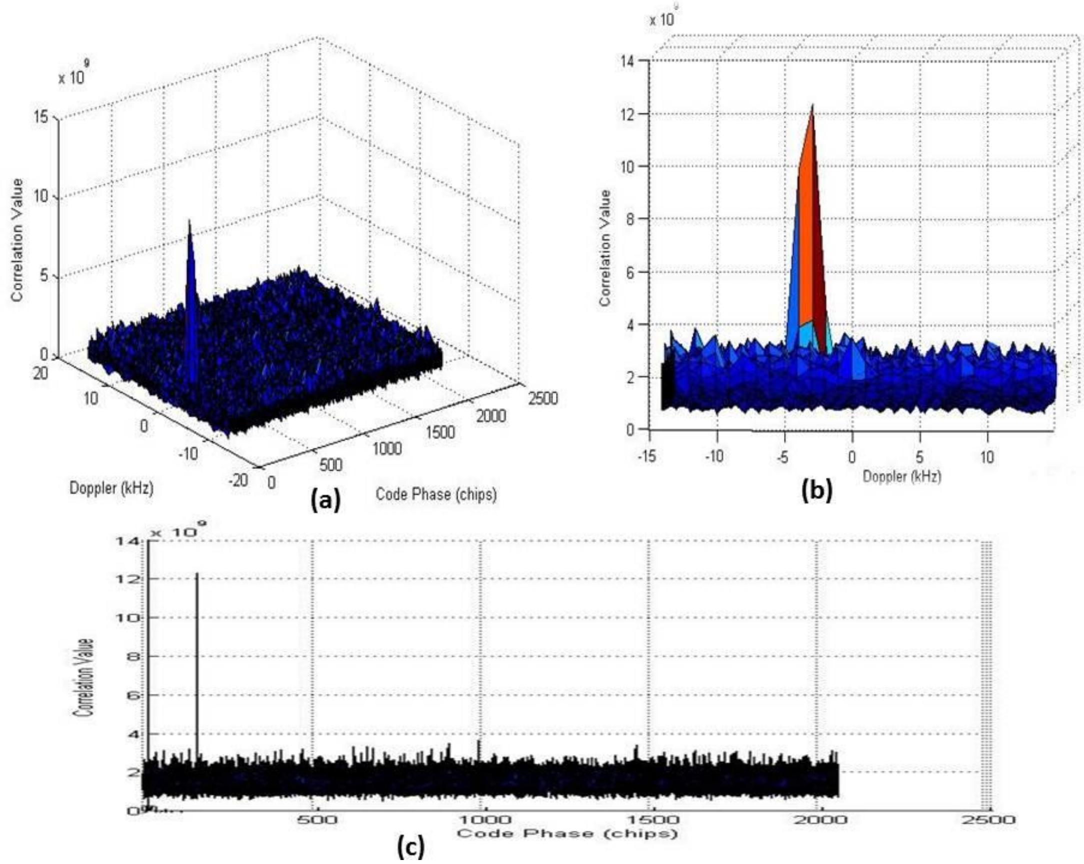


Fig. 6.11 Correlation of satellite with the estimated code delay and Doppler

(a) Acquisition of Sat-10 **(b)** Doppler of Sat-10 **(c)** Code phase of BDS Sat-10

6.4 Acquisition of BeiDou-2 Data Collected at Ohio State, USA

Acquisition of Beiodu-2data which is collected from Ohio State is used for Acquisition of receiver. Sky plot of Ohio State[49] is given in Fig 6.12and our receiver has acquired the same satellite numbers 11,13 and 14as shown in the result given in Fig 6.13

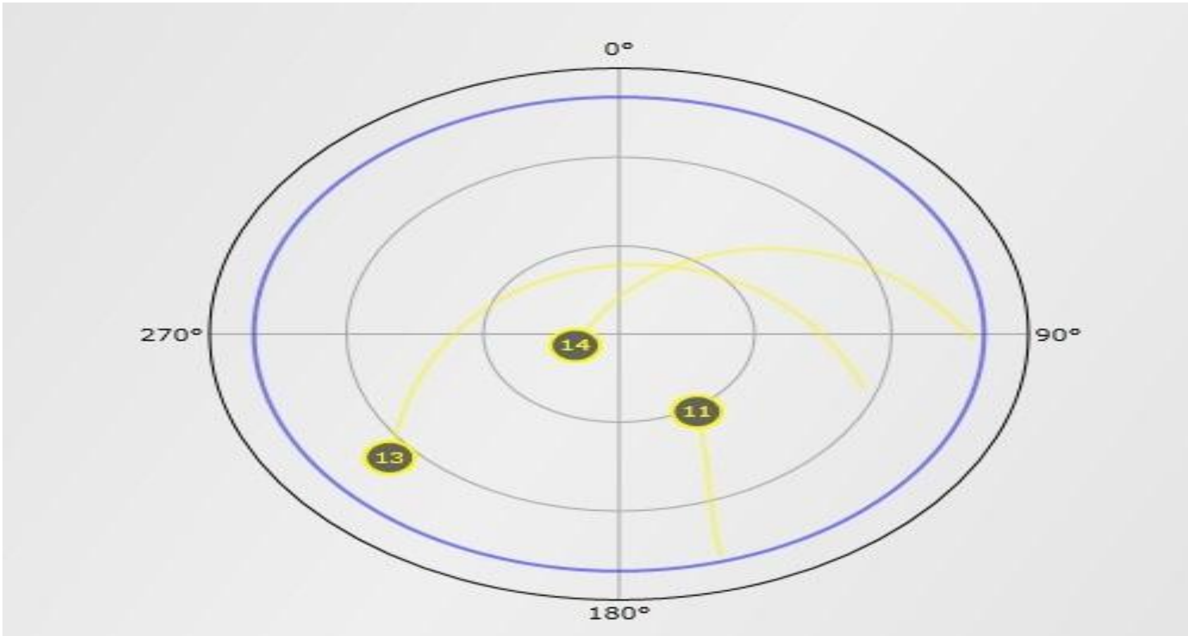


Fig 6.12 Sky Plot of Beiodu-2 data showing the visibility of satellite PRN number 11,13 and 14 over Ohio State, USA

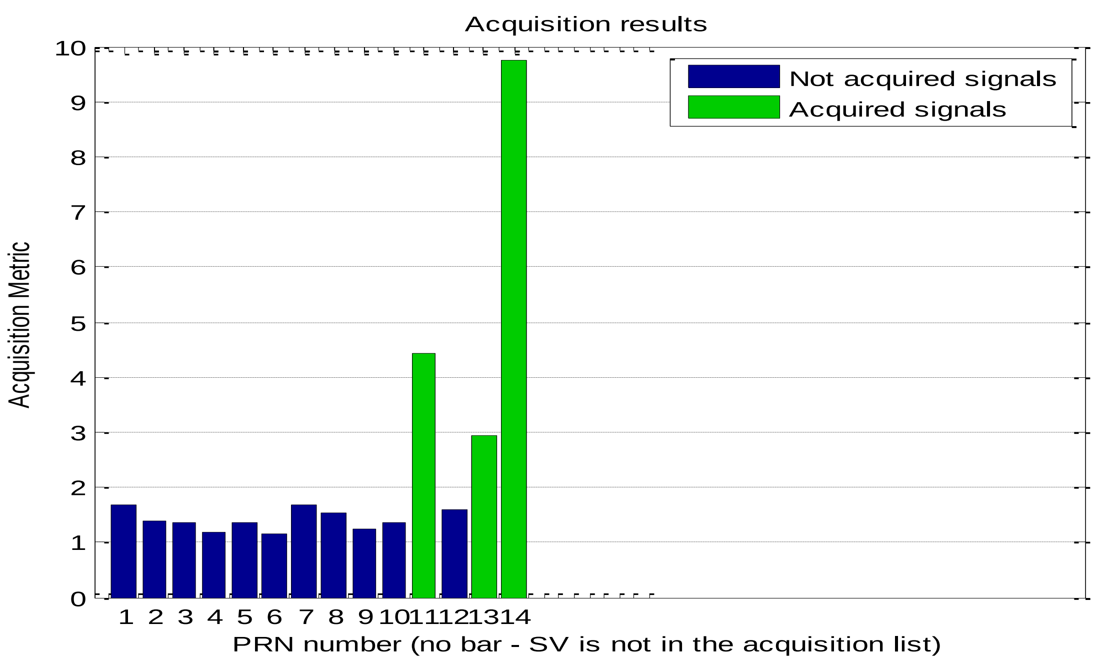


Fig 6.13 Acquisition of BeiDou-2 B1I Signal

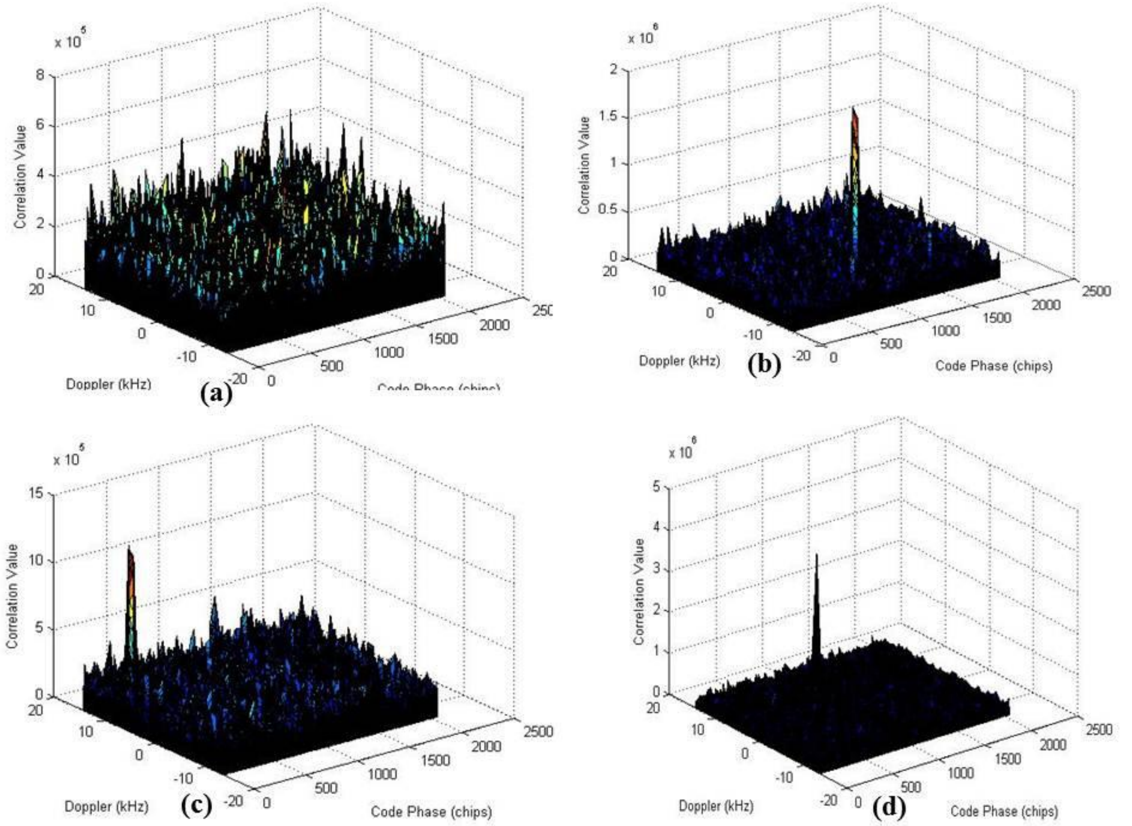


Fig 6.14 Correlation of satellite with the estimated code delay and Doppler **(a)** No Acquisition **(b)**Acquisition of Sat-11**(c)**Acquisition of Sat-13**(d)**Acquisition of Sat-14

Minimum 3 satellites are required for calculation of PVT, however BeiDou-2 GNSS is under construction and will have 35 satellites on its completion. Fig 6.15 shows the acquisition of BeiDou-2 satellite number 11,13 and 14 with respect to the estimated Doppler and Code delay. The given data has been downloaded from the OHIO University Research site[43].The results have been verified through site [49] which is used for GNSS planning. Tracks of BeiDou Satellite over Ohio State[49] from where data was collected is given in Fig 6.15.

Fig 6.15 Tracks of Beiodu-2 Satellites over Ohio State

6.5 CNR vs Acquisition

Acquisition of Beiodu-2 simulated data is carried out. The power level of the satellite with PRN number 1 is varied from 3 to 8dbW and Additive Wide Gaussian Noise(AWGN) is randomly generated. Monte Carlo simulation is carried out in which CNR is varied from-22to -18.5dbW and acquisition metrics is plotted.

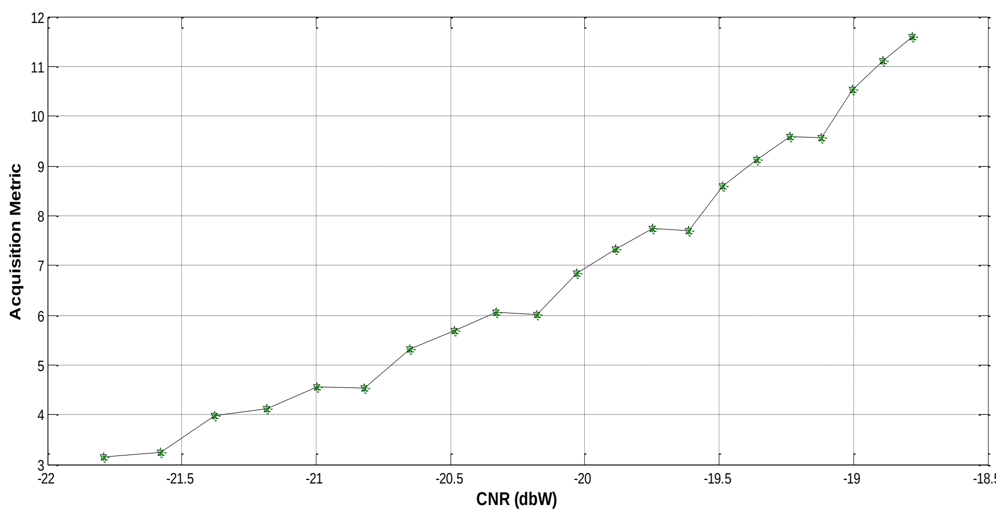


Fig 6.16 Graph of CNR vs Acquisition metric

The given graph in Fig 6.16 shows that as the CNR is increased , the acquisition metric/ correlator output performance has been improved[50,51].

PRN Sequence	2046 Chips
Chip rate	2.046 Mcps
AWGN	Random
CNR	-22 to -18.5dbW

Table 6.1 Parameters for CNR vs Acquisition performance

6.6 ICR vs Acquisition

Acquisition of simulated Beiodu-2 data is carried out in which power of of satellite with PRN 2 is varied from 3 to 8dbW. Acquisition plot with initial value is given in Fig 6.17 in which power of all satellites is switched off and only neighboring satellites which are PRN 1 and PRN 2 are considered.

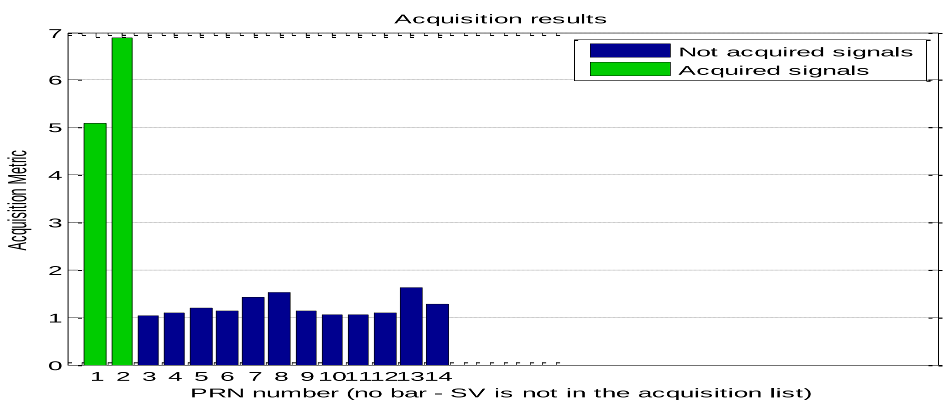


Fig 6.17. Only two satellites with PRN number 1 and 2 are considered to monitor the effect of Interference to Carrier ratio on acquisition performance.

All other satellites are switched off. Acquisition of satellite with PRN 1 is monitored while power of neighboring satellite PRN 2 is increased.

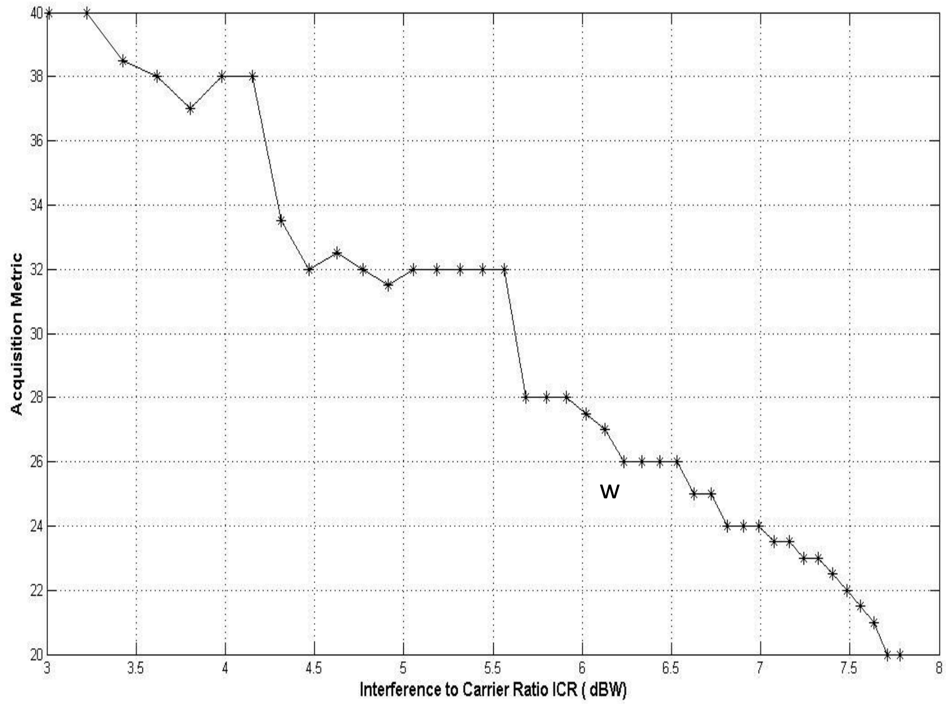


Fig 6.18 . Graph of ICR verses Acquisition metric

Accordingly graph is plotted which is given in Fig 6.18 in which it is shown that as the carrier to interference ratio is increased the acquisition metric/ correlator output will be degraded. Parameters of scenario-5 are given in the following table:

PRN Sequence	2046 Chips
Chip rate	2.046 MCps
AWGN	Nil
ICR	3 to 8 dbW

Table 6.2 Parameters for ICR vs Acquisition Performance

6.6 Doppler vs Acquisition

Acquisition of the simulated BeiDou-2 is carried out in the presence of Doppler. In this the power of the satellite is kept constant with no AWGN and the Doppler frequency is varied from 500 Hz to 10000 Hz of the satellite with PRN number 1.

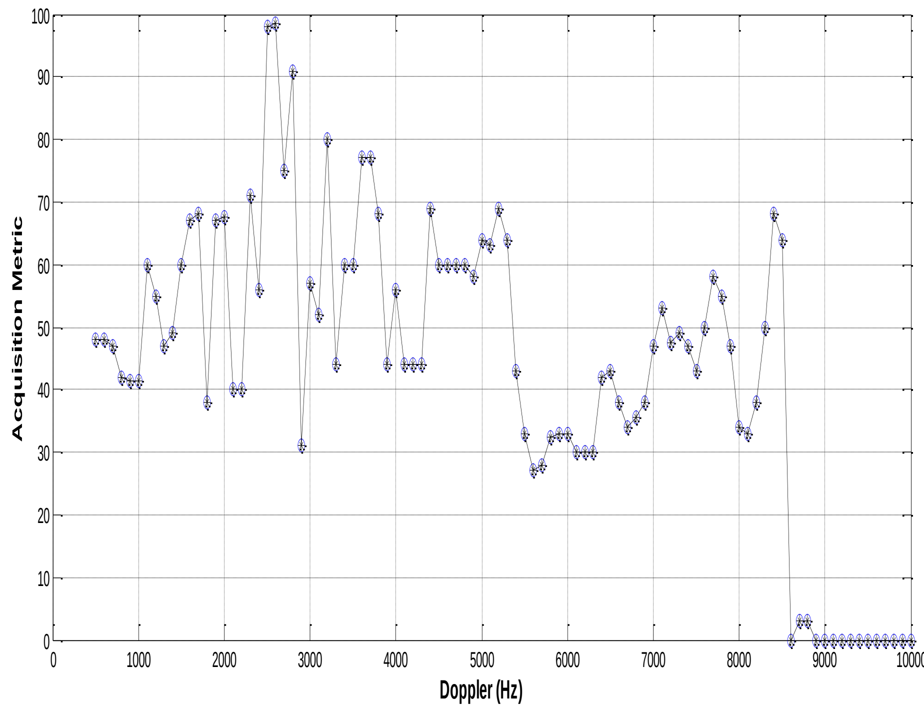


Fig 6.19 Graph of the effect of Doppler on Acquisition performance.

Accordingly the performance of the acquisition algorithm is monitored and plotted in Fig 6.19 which is showing a random pattern, however at 2500 to 2800 Hz , it is is showing the best performance. However after 9000 Hz , it is showing no acquisition. Parameters for Scenario-6 is given in the Table 6.3.

Doppler	500 to 10000 Hz
PRN Sequence	2046 Chips
Chip rate	2.046 Mcps
AWGN	Nil
Power of satellite 1 and 2	3and 4dbW

Table 6.3 Parameters for Acquisition performance vs Doppler

6.7 Conclusion

In this chapter we have successfully acquired the actual and simulated data of B1I signal of BeiDou-2 and performance based measurement is also carried out in which we have acquired the signal in the presence of Doppler , Interference and Noise. Realistic environment of satellite acquisition is carried out with the BeiDou-2 simulator.

Chapter 7

Conclusion and Future works

7.1 Conclusion

During the elaboration of this work, many obstacles were overtaken leading to a fully functional, tested and validated Beiodu-2GNSS signal acquisition system. This work was divided in the study, design and test/validate of a Beiodu-2 Acquisition in which a PC based Monte Carlo simulation and Sky plots were also used to validate the results .Chinese satellite navigation system BeiDou-2 and Europeans satellite navigation system Galileo are under development. Therefore, the research for developing GNSS receivers for Galileo and BeiDou-2 is experiencing a new upsurge. With the current functionality of the BeiDou-2 Chinese satellite navigation constellation, efforts have been focused on 1561.098 MHz B1I signals for software receiver implementation.

In this Thesis we have implemented the Acquisition of the Beiodu-2 B1I signal using Matlab and have used DVB-T device with active antenna as a frontend for collection of Beiodu-2 B1 signal. In addition BeiDou-2 GNSS signal generator is also designed and implemented in Matlab for algorithm testing and development. BeiDou-2 GNSS signal generator is also carrying out the performance verification of the Acquisition algorithm in the presence of Doppler , interference and thermal noise. We can introduce each of these impairments in a scenario-specific combinations and individually to improve the design and to address the trouble shooting. The designed Beiodu-2 signal simulator gives us the ability to adjust the power of 14 simulated BeiDou signal power levels and same can be increased upto 37 satellites. More realistic reproduction of the environment is offered by varying the power levels of different satellites . With the addition of AWGN and varying the power level of signal, the performance of the BeiDou receiver has been measured with respect to CNR , CIR and correlater output. Doppler effects have also been added through the Simulator and results have been drawn.

7.2 Future Work

There are many other improvements as well as new developments that can be made in the BeiDou-2 GNSS receiver area . The creation of a study and development group on BeiDou-2 receiver would be of the great interest.

- Work on tracking and computation of position velocity is required
- Hard ware implementation of the complete BeiDou-2 receiver is required to be carried out

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