Technical Report of GNSS Software receivers: baseband processing with FPGA

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Contents

List of Figures

List of Tables

1. Introduction

1.1 GNSS

Satellite navigation system with global coverage is called as global navigation satellite system or GNSS. GNSS (Global Navigation Satellite System) is a satellite system that is used to find the geographic location of a user's receiver anywhere in the world. It allows small electronic receivers to determine their location (longitude, latitude, and altitude) with an accuracy up to less than one meter using signals, transmitted along a line-of-sight by transmitter from satellites. Satellite-based navigation systems use a principle of triangulation to locate the user, through calculations using the information transmitted by a number of satellites. Each satellite transmits coded signals [1].

Global Position System, developed and operated by the Department of Defence of United States America, is the first GNSS system. GLONASS, is an another satellite based navigation system developed and operated by Department of Defence of Russia. A simple GPS receiver will be one of the important features for many hand held devices, like mobile phones [1].

The original motivation for satellite navigation was for military applications. However, user countries all over the world which have been extensively using the GPS, or GLONASS for civilian applications have strongly felt the need to develop and launch their own regional/global navigation systems along with augmentation systems so that they may operate with or without collaboration from GPS or GLONASS. This has lead to the evolution of Global Navigation Satellite System that will have universal accessibility. GNSS refers not only to GPS, GLONASS, Galileo (of Europe), COMPASS (of China), QZSS (of Japan) and IRNSS (of India) along with their respective augmentation systems [1] [2].

Sometimes the GPS signals are not available to find out the position, due to blockage of signals by buildings, trees etc. Therefore, if a single receiver is developed which can be used to locate the position, using the signals of any GNSS system, or with the signals of two or more GNSS systems, availability and continuity of obtaining the receiver position increases because any four satellites of any system, which are visible can be used to locate the position.

1.2 GNSS software Receivers

GNSS receivers have been traditionally implemented in hardware. A hardware GNSS receiver is conceived as a dedicated chip that have been designed and built with the only purpose of being a GNSS receiver. The presently available traditional GNSS receivers are hardware based and are available for GPS and GLONASS.

GPS and GLONASS hardware based receivers are not flexible and cannot be easily upgraded to acquire the signals from other GNSS systems like Galileo and Compass also the complexity of receiver increases because of the new signals structures and algorithms, introduced to improve the performance.

In general conventional GNSS receivers' architecture can typically be partitioned into three distinct components. An analog section, responsible for the analog signal conditioning, the second component is a dedicated hardware subsystem (base band processor) to derive measurements from the received signal, and final component is a programmable processor, it is responsible for processing the accumulated measurements.

In a software GNSS receiver, all digital processing is performed by a general purpose microprocessor or DSP or FPGA. In this approach, a small amount of inexpensive hardware is still needed, known as the frontend, which digitizes the signal from the satellites. The microprocessor can then work on this raw digital stream to implement the GNSS functionality. It also offers various advantages like,

- Software approach removes the nonlinear, temperature-dependent and age dependent components of the hardware receiver.
- A software receiver can provide more evolution and testing flexibilities. Some systems may collect complex data in both in-phase (I) and Qudrature (Q) channels while others use real data from one channel. The output data from these different platforms can be processed by the same software receiver. Both complex and real data can be generated by the software receiver with slight modifications .the software receiver can also adapt to data digitized with various sampling frequencies. The performance of different algorithms can be compared without any hardware development.

- A software receiver can provide researchers and developers with more evaluation and testing flexibility, it provides and effective simulation environment. New algorithms can be developed for the software receiver to solve problems, such as jamming signals, without altering the hardware components.

The software receivers are more feasible particularly for the wireless environment compared to the hardware receivers. GNSS Software receivers allow a huge flexibility: many features of the receiver can be modified just through software. This provides the receiver with adaptive capabilities, depending on the user requirements and working conditions. In addition, the receiver can be easily upgraded via software. Under some assumptions, Software GNSS receivers can be more profitable for some applications. From these reasons, flexibility is seen as an asset for a software receiver.

1.3 Motivation

The availability of real-time satellite signals used in software receivers has opened up a wide range of research opportunities in GNSS world. Many commercial devices use GPS navigation system and still a lot of research is going on this. The GNSS software receiver first takes the complete available IF data and processes for acquisition, tracking and demodulation. Later, it will find out the position of receiver for every milli second. Therefore it can be neither used for real time nor for time synchronous processing. It will be useful for offline analysis of IF data for computing the receiver position. However it can be converted in to Time synchronous with few modifications and later as a real time software receiver.

2. GPS Architecture and Signal Structure

2.1 Introduction

The basic principle of operation, Architecture, and signal structure of GPS are essential to develop a GPS receiver, which are explained in this chapter.

2.2 Principle of Operation

The basic working principle of GPS navigation system is to measure the distance between the known satellite and GPS receiver at user side, then analyses and confirms the specific geographic position of the GPS receiver. To calculate the position of the receiver, timing information is required. The time information is placed in the signal and broadcasted by the satellite. The signal contains data that a receiver uses to compute the locations of the satellites and to make other adjustments needed for accurate positioning.

Suppose the GPS signal travels to the ground at the speed of light, it still takes a measurable amount of time to reach the receiver. The receiver then calculates the distance to the satellite by measuring the difference between the time when the signal is received and the time when it was sent, and multiply by the speed of light. The receiver must account for propagation delays, or decreases in the signal's speed caused by the atmosphere. The receiver received signal is needed to extract the navigation message and timing information to determine the location using either hyperbola or triangulation principles. This principal is fundamental to GPS.

$$\text{Propagation time} = \text{Time signal reached receiver} - \text{Time signal left satellite}$$

$$\text{Distance} = \text{speed of light} \times \text{Propagation time}$$

Triangulation is the process, which is based on the location of satellites in space as reference points. To determine the user position, three satellites and three distances are required that is shown in Figure2.1. Imagine an unknown person standing somewhere on Earth with three satellites in the sky above to that person. If unknown person know how much distance from satellite A, then he must be located somewhere on the sphere. If unknown person do the same for satellites B and C, he can be located somewhere by seeing where the three spheres intersect. The intersection of these three distances should indicate the user's position.

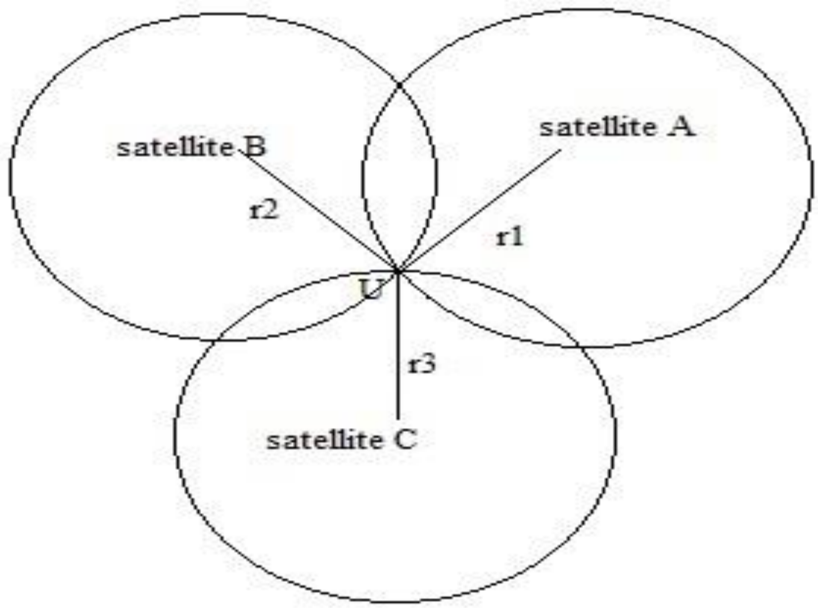

Figure 2.1: Triangulation

However three satellites are needed to determine latitude and longitude, while a fourth satellite is necessary to determine altitude without any clock error. However the satellite and receiver are controlled by separate clocks. The satellites are set as accurately as possible with an atomic clock, and are assumed to be synchronized with one another. It is important when the time to be measured precisely in order to accurately measure distance, suppose if an error of the synchronization of the two clocks of one microsecond creates an error of 300 meters. By taking a measurement from a fourth satellite, the receiver avoids the need for an atomic clock and provides accurate position. Thus, the receiver uses four satellites to compute latitude, longitude, altitude, and time. Now this information is enough to discuss to signal structure of GPS.

2.3 Architecture of GPS

For the GPS to function smoothly there are three important segments. They are:

1. The Space Segment

2. The Control Segment

3. User Segment

2.3.1 Space Segment

The Space Segment constitutes of 31 satellites as shown in Figure 2.2 at an altitude of about 20,150 km above the Earth's surface. These satellites are arranged as 8 each in three circular orbital planes, but this was modified to 6 planes with 4 satellites each. The orbital planes are centered on the Earth, not rotating with respect to the distant stars. These orbital planes are inclined to the Earth's equatorial plane at an angle of 55° (tilt relative to Earth's equator) and are separated by 60° right ascension of the ascending node (angle along the equator from a reference point to the orbit's intersection). The orbits are arranged so that at least six satellites are always within line of sight from almost everywhere on Earth's surface. The orbital plane locations are defined by the longitude of the ascending node while the satellite location by the mean anomaly. These satellites are at such a height and in such orbits such that there are at-least four satellites visible to a user at any location and at any given time. At a time one can however receive signals from 7 to 9 satellites.

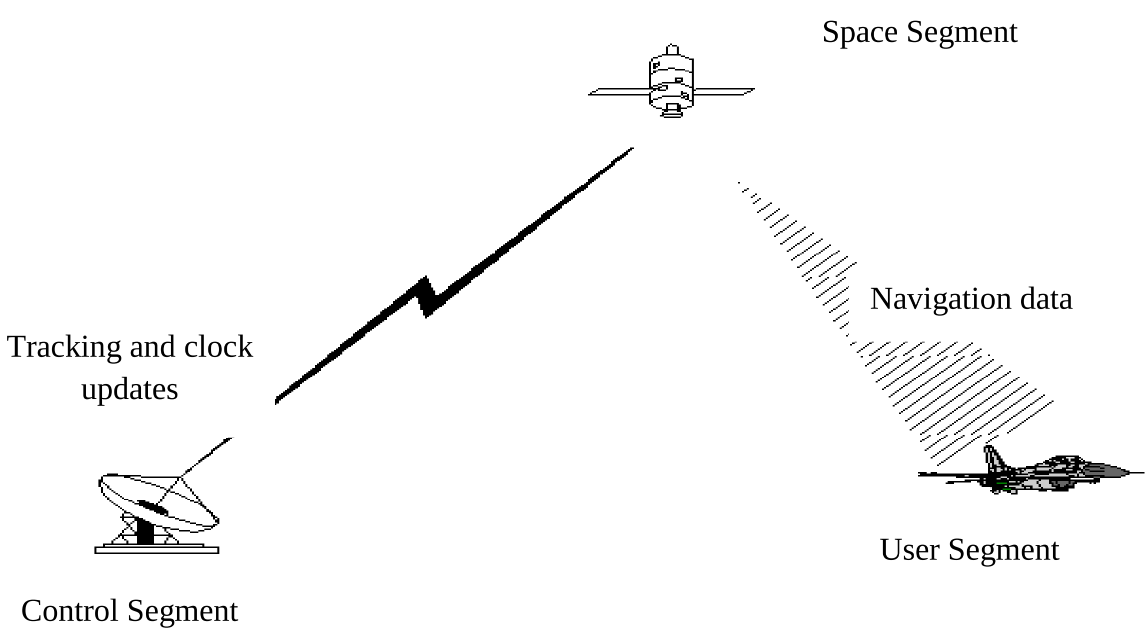

Figure 2.2: GPS Segments

The Satellite Vehicles (SVs) will travel at a velocity of 3.9km/s. They orbit at altitudes of about 20,150kms from surface of earth and 11hours 58 minutes 2.01seconds to orbit one time (Leick, 2004). The advantage of greater altitude is that the orbits will be less affected by the irregularities caused by unequal distribution of mass of the earth. The satellites continuously orient themselves to ensure that their solar panels stay pointed towards the sun, and their antennas point toward the earth (Parkinson and Spilker, 1996). The transmitted signals are controlled by highly accurate atomic clocks.

2.3.2 Control Segment

The Control segment consists of Master Control Station (MCS) at Colorado Springs, five Monitor Stations located around the world at Hawaii, Kwajalein, Ascension Island, Diego Garcia and Colorado Springs, Colorado, along with monitor stations operated by the National Geospatial-Intelligence Agency (NGA) ensure maximum satellite coverage and ground antennas. The tracking information is sent to the Air Force Space Command's master control station at Schriever Air Force Base in Colorado Springs, which is operated by the 2nd Space Operations Squadron (2 SOPS) of the United States Air Force (USAF). These 2 SOPS contacts each GPS satellite regularly with a navigational update (using the ground antennas at Ascension Island, Diego Garcia, Kwajalein, and Colorado Springs).

Figure 2.3: GPS Satellite Constellations

These updates and synchronize the atomic clocks on board satellites to within a few nanoseconds of each other, and adjust the ephemeris of each satellite's internal orbital model. The updates are created by a Kalman filter which uses inputs from the ground monitoring stations, space weather information, and various other inputs [1] [2].

The functions of the Operations Control Segment include maintaining the satellite orbital position, and monitoring the health of the satellite constellation. The health includes parameters like the power, fuel levels among others. The ground stations make pseudo range measurements by passively tracking the satellites. This updated information is called TT&C (Telemetry, Tracking and Command) data. This information for each satellite is uploaded by a ground up link antenna when that particular satellite is in view of this antenna [2].

2.3.3 User segment

GPS receivers are composed of an antenna, tuned to the frequencies transmitted by the satellites, receiver-processors, and a highly-stable clock (often a crystal oscillator). They may also include a display for providing location and speed information to the user. A receiver is often described by its number of channels; this signifies the number of satellites it can monitor simultaneously. Originally limited to four or five, this has progressively increased over the years so that, as of 2006, receivers typically have between twelve and 76 channels to receive satellite signals and estimate the distance from satellite. Front end antenna and RF unit receives the signal and after sufficient level of amplification, it will be digitized, (Parkinson and Spilker, 1996). The digital GPS receiver applies DSSS correlation technique and extracts the base band data. GPS processor uses minimum four such channels data and calculates its location. Since the location of each GPS satellite is known, the receiver's location can be determined by "triangulating" the distances from several satellites [1] [2].

2.4 GPS Signal Structure

In order to design a software-defined single frequency GPS receiver it is necessary to know the characteristics of the signal and data transmitted from the GPS satellites and received by the GPS receiver antenna. The GPS signals are transmitted on two radio frequencies in the UHF band. The UHF band covers the frequency band from 500MHz to 3 GHz. These frequencies are referred to as L1 and L2 and are derived from a common frequency.

$$f_0 = 10.23\text{MHz}:$$

$$L1 = 154\ f0 = 1575.42\ \text{MHz},$$

$$L2 = 120\ f0 = 1227.60\ \text{MHz}\ .$$

The signals are composed of the following three parts:

2.4.1Carrier:

In GPS system all satellites are having same frequency which is 1575.42 MHz for L1 band and similarly L2 band having 1227.60MHz. These carrier frequencies are modulated with data signal and C/A code using BPSK modulation.

In receiver segment the received signal having very high frequency so it is very difficult to signal processing due to complexity of the signal. In order to achieve this we need down conversion of the signal from higher carrier frequency to intermediate frequency. So in our case we are down converting to 9.548 MHz as shown in below.

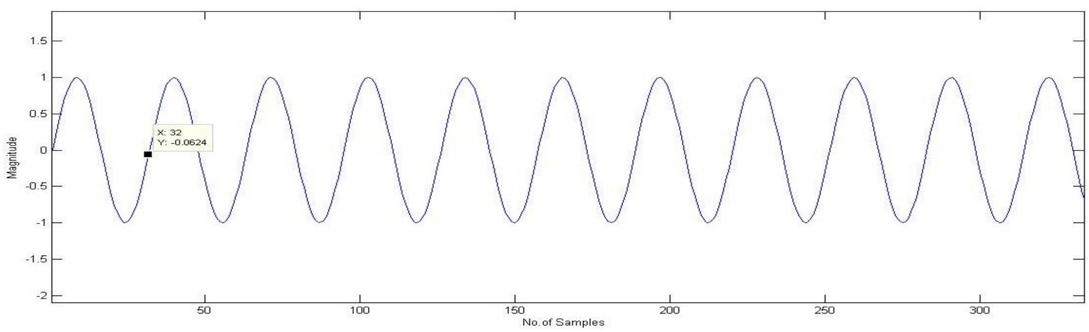

Figure 2.4: sinusoidal carrier wave generation

2.4.2 Navigation data:

The navigation data contain information regarding satellite orbits. That information is uploaded to all satellites from the ground stations in the GPS Control Segment. The navigation data have a bit rate of 50 bps.

2.4.3 Spreading sequence:

Each satellite has two unique spreading sequences or codes. The first one is the coarse acquisition code (C/A), and the other one is the encrypted precision code (P(Y)). The C/A code is a sequence of 1023 chips. The code is repeated each ms giving a chipping rate of 1.023 MHz. The P code is a longer code with a chipping rate of 10.23 MHz, it repeats itself each week starting at the beginning of the GPS week which is at Saturday/Sunday midnight. The C/A code is only modulated onto the L1 carrier while the P(Y) code is modulated onto both the L1 and the L2 carrier.

2.4.4 Generation of C/ A Code

GPS Ranging code is called C/A code. The C/A code is referred as Coarse/Acquisition or Clear/Access. The GPS C/A signals belong to the family of Pseudo-random noise (PRN) codes known as the Gold codes. Each satellite has two unique spreading sequences or codes. The first one is the coarse acquisition code (C/A), and the second one is the encrypted precision code (P(Y)). The C/A code is a sequence of 1023 chips.

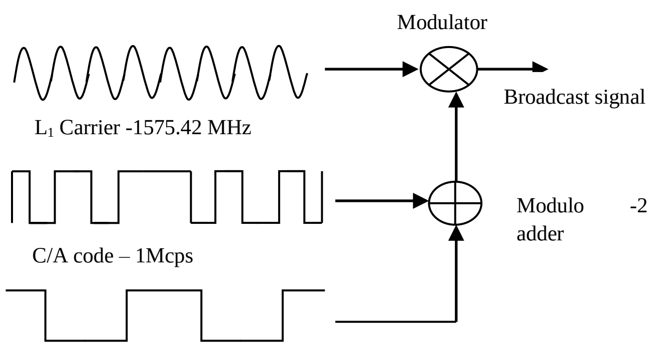

Figure 2.5: GPS signal modulation

The code is repeated each one millisecond giving a chipping rate of 1.023 MHz. The P code is a longer code with a chipping rate of 10.23 MHz. It repeats itself each week starting at the beginning of the GPS week which is at Saturday/Sunday midnight. Fig 2.5 shows the GPS modulation scheme. Only the C/A code is modulated onto the L1-1575.42 MHz carrier while the P(Y) code is modulated on both L1-1575.42 MHz and L2-1227.60 MHz carrier.

The PRN sequence is generated from the product of two shift registers, G_1 and G_2 1023-bit PRN sequence generators. Both G_1 and G_2 are generated by a maximum-length linear shift register of ten stages and are operated at 1.023 MHz clock.

Fig 2.6 shows the architecture of two generators, G_1 and G_2. Each generator has its own linear feedback shift register (LFSR) and proper feedback, to generate random sequence. The MSB of G_1 is considered as the G_1 output, maximum length sequence (MLS), whereas the G_2 output is taken from the phase selected bits of G_2 LFSR, which are referred to as the code phase selections through another modulo-2 adder. This G_2 output is a delayed version of the MLS output. The delay time is determined by the positions of the two output points selected [2].

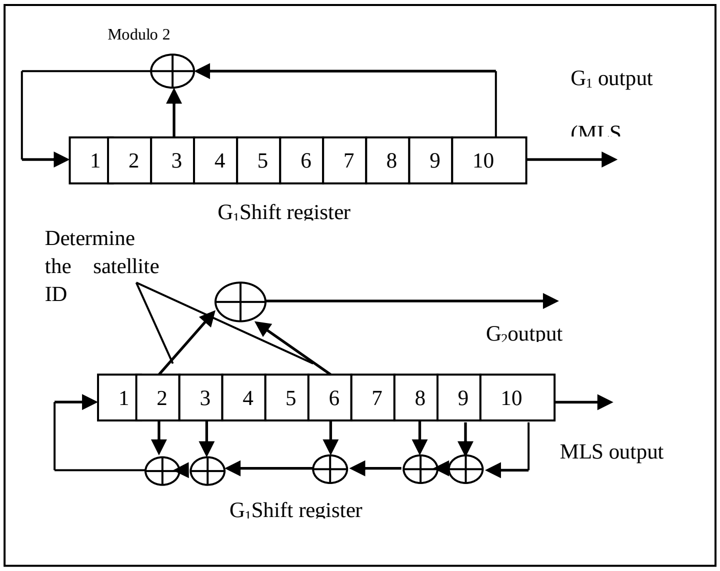

Figure 2.6: G_1 and G_2 maximum length sequence generators

If the linear feedback shift register has *n* bits, the length of the sequence generated is 2^n*-1*. In this application, as both shift generators in G_1 and G_2 have ten bits, the sequence length is 1023. The feedback circuit is obtained through modulo-2 adders. The operating rule of the modulo-2 adder is when the two inputs are the same the output is zero, otherwise it is one. The positions of the feedback circuit determine the output pattern of the sequence. The corresponding polynomial can be written as G_1: $1+x^3+x^{10}$. The feedback of G_2 is from bits 2, 3, 6, 8, 9, 10 and the corresponding polynomial is G_2: $1+x^2+x^3+x^6+x^8+x^9+x^{10}$ [2].

The C/A code generator is developed using G_1 and G_2 generators as shown in fig 2.7. 1.023 MHz clock is used to initiate both the generators. Another modulo-2 adder is used to generate the C/ A code using G_1output and G_2output. After completing one C/A code sequence for 1023 bits, G_1 and G_2 generators are forced to be loaded with initial values, i.e., all ones using reset circuit.

Identification of each satellite is determined by choosing the two phase selected bits of the G_2 generator. For example, first satellite is determined by selecting second and sixth bits of G_2. The details of identification numbers of all satellites can be found in [2], [3]. There are 37 unique output positions. Among these 37 outputs, 32 are utilized for the C/ A codes of 32 satellites, but only 24 satellites are in orbit. The other five outputs are reserved for other applications such as ground transmission [2], [3].

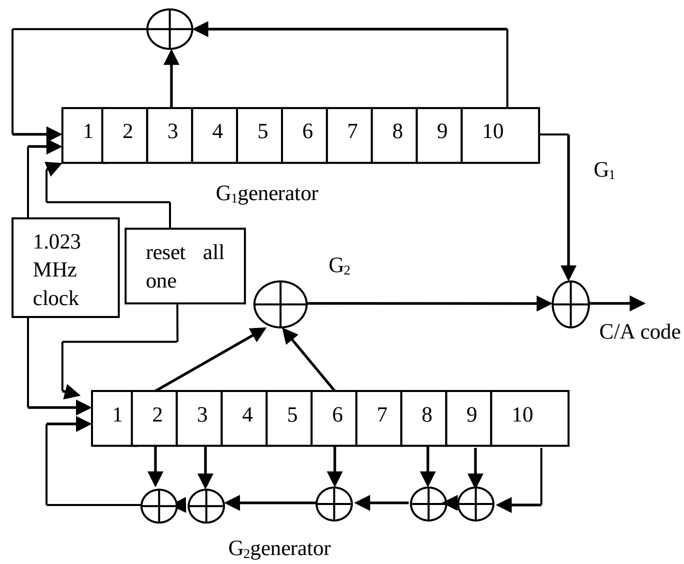

Figure 2.7: C/A code generator

The Modulo-2 addition is implemented in digital logic as mentioned in Table 2.1. In order to reduce the computational complexity to implement in Matlab, modulo-2 addition is replaced with normal multiplication, as given in Table 2.2 [1].

Table 2.1 Modulo-2 addition

Input1	Input 2	Output
0	0	0
0	1	1
1	0	1
1	1	0

Table 2.2 Normal multiplication

Input1	Input 2	Output
-1	-1	1
-1	1	-1
1	-1	-1
1	1	1

(b) C/A code Generation at Different Sampling Frequencies

The C/A code is a 1,023 bits long pseudorandom number (PRN), which when transmitted at 1.023Mbps, repeats every millisecond. Pseudorandom numbers only match up, or strongly correlate, when they are exactly aligned. Each satellite transmits a unique PRN code, which does not correlate well with any other satellite's PRN code. Programmable C/A code generator can produce C/A code depending on the phase select bits. GPS satellites generated C/A codes having 1023 chips/ms at clock rate1023kbps this code repeat every 1ms, each group of 1023 chips called as C/A code and it is vary with the different satellites.

The generated C/A code for the 19^{th} satellite having 1023 chips/ms is as fallows

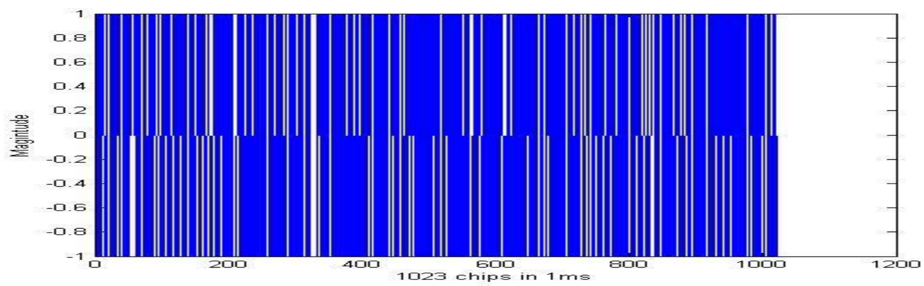

Figure 2.8: C/A code of 19^{th} satellite

The generated C/A code having 1.023 MHz sampling frequency and 1.023 MHz code frequency as fallows in terms of C/A code vs time.

$$\frac{1}{Sampling\ frequency} \times (0{:}\,1024 - 1)$$

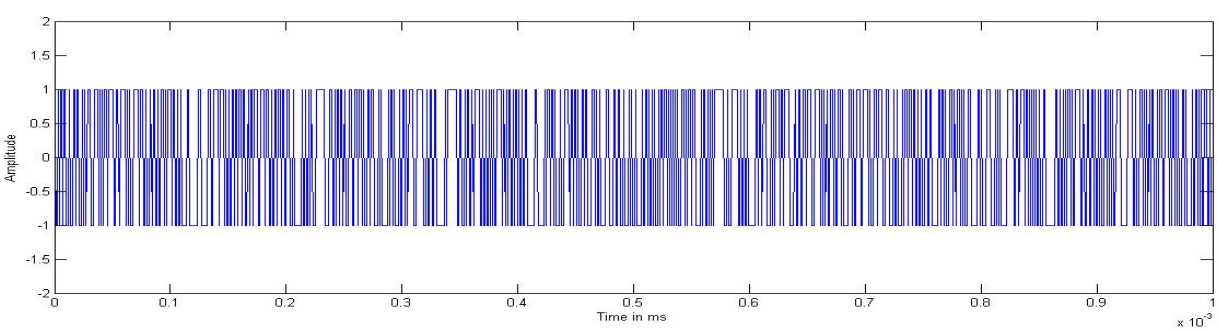

Figure 2.9: C/A code vs Time

we are applying the FFT to the C/A code of 19^{th} Satellite, when we are applying the FFT it converts time domain to frequency domain because in time domain the signal analysis is complex but in terms of frequency domain the frequency analysis can be easy so that we are converting the signal in to frequency domain. When C/A code sampled at 1.023MHz, it generates 1023kcps means 1023 chips/ms so each sample takes 1 kHz frequency resolution

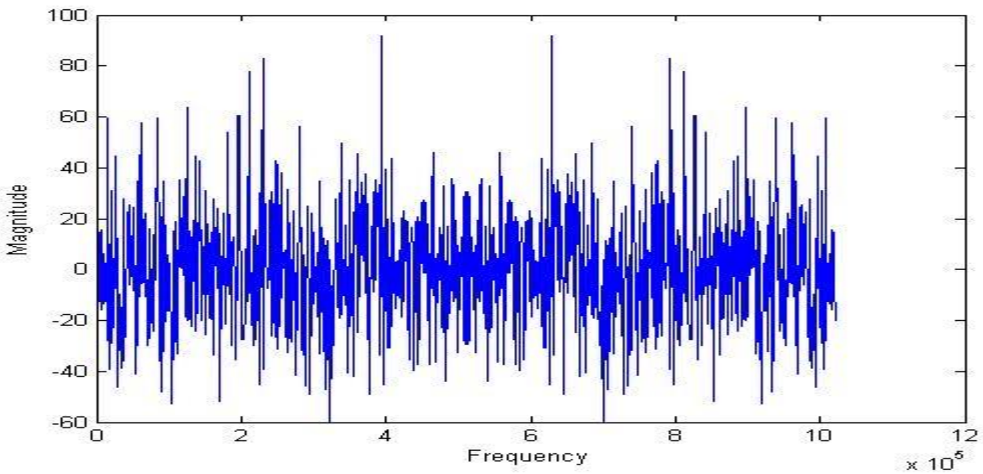

Figure 2.10: Frequency domain representation of C/A code sampled at 1.023MHz

We can get Magnitude of the above spectrum by applying the absolute FFT. The magnitude of the above spectrum as fallows

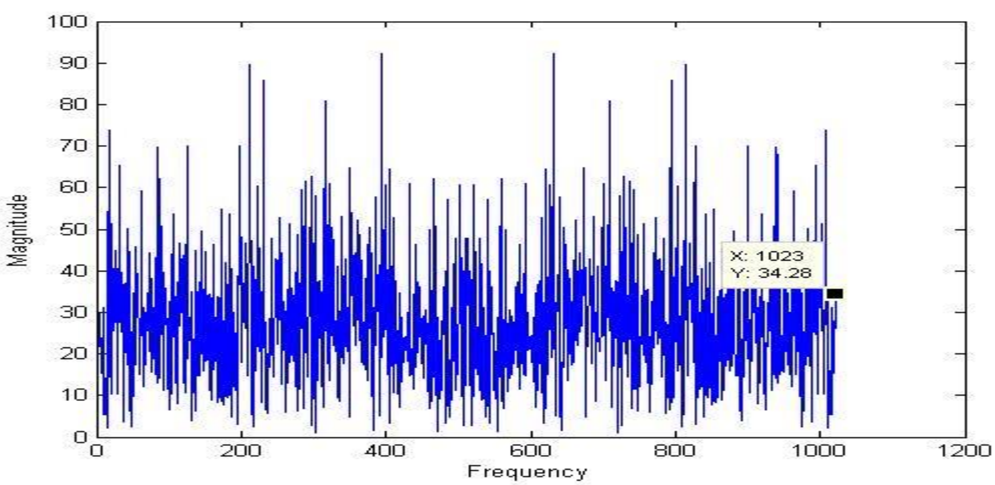

Figure 2.11: Frequency domain representation of C/A code

When the C/A code is sampled at 2.046MHz, maximum frequency component will be having at 1.023MHz and the spectrum of 2.046MHz sampled C/A code is shown in below figure.

$$F_s \geq 2F_{max} = 1.022\text{MHz} \geq 2\times1.023\text{MHz}$$

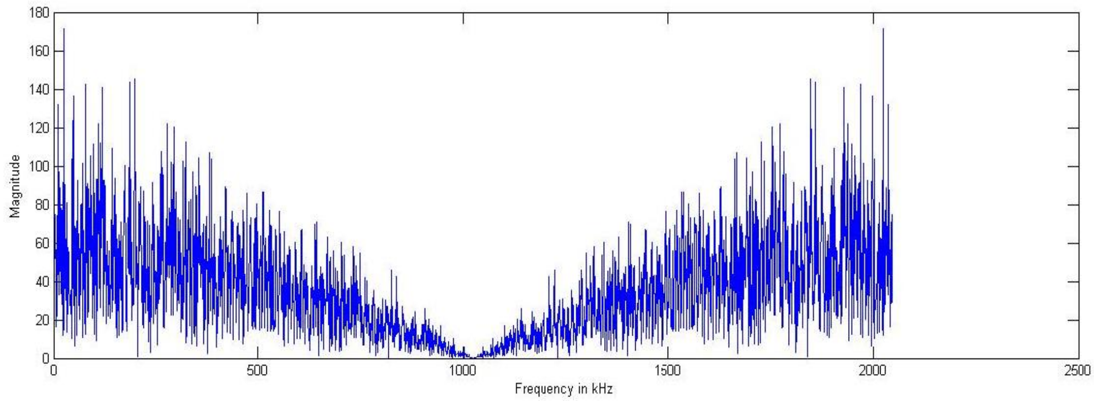

Figure 2.12: FFT of C/A code at sampling frequency 2.046MHz

Similarly if C/A code of 19th satellite is sampled at 5.115MHz means C/A code sampled to 5 times of its code frequency so here each chip will be replaced with 5 samples and the spectrum of 5.115MHz sampled C/A code is shown in below figure.

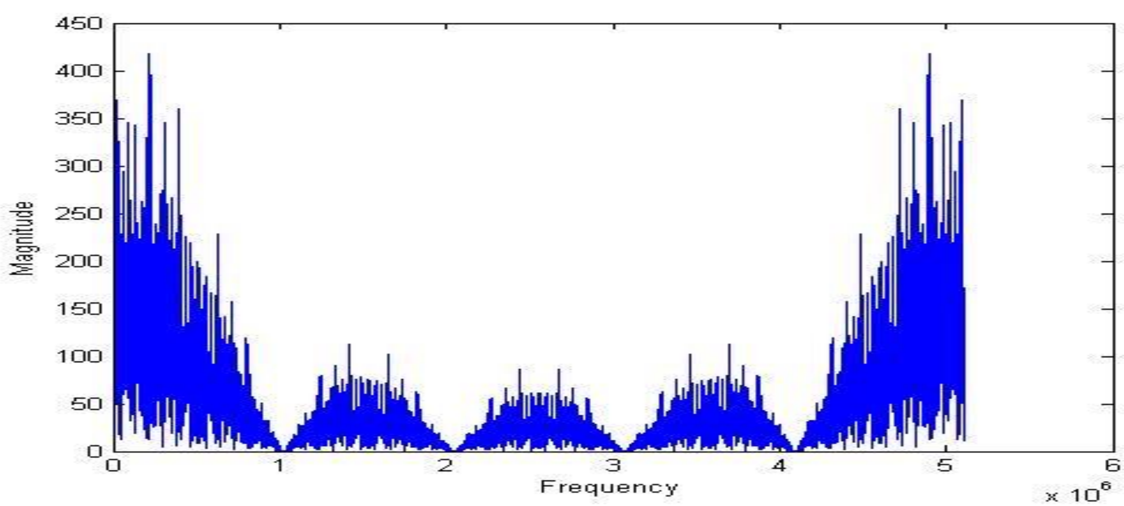

Figure 2.13: FFT of C/A code at sampling frequency 5.115MHz

The C/A code of 19th satellite is sampled spectrum at 38.192MHz shown in below. The C/A code of 1.023MHz is having samples 38.192MHz, so each chip of C/A code having 1 KHz resolution.

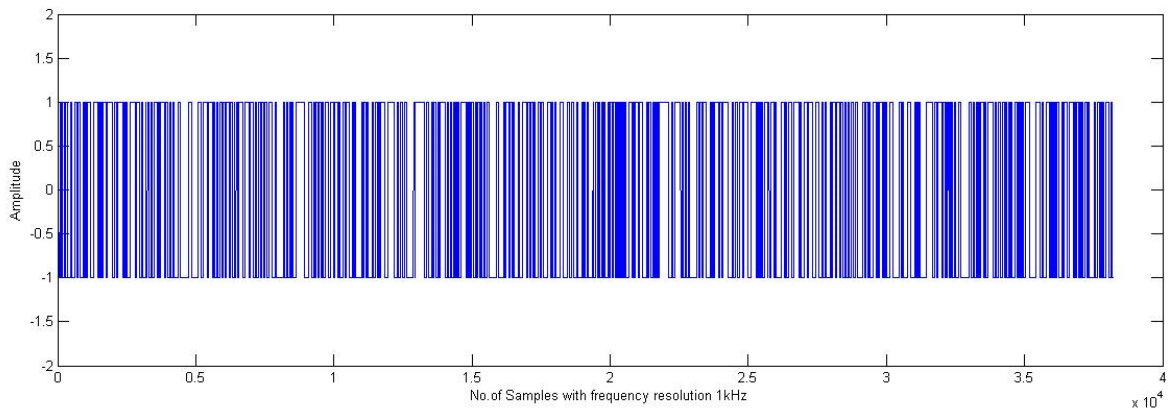

Figure 2.14: Sampled C/A code at 38.492MHz

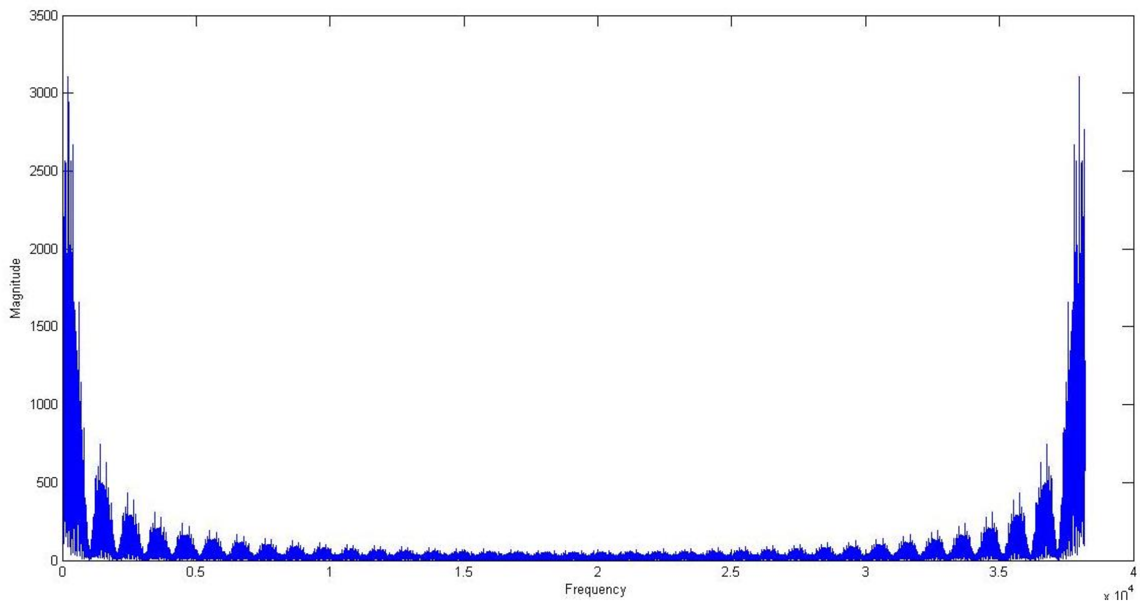

Figure 2.15: FFT Spectrum of 38.492MHz sampled C/A code

(c) Correlation Properties of C/ A Code

One of the most important properties of the C/A codes is their correlation result. High autocorrelation peak and low cross-correlation peaks can provide a wide dynamic range for signal acquisition. In order to detect a weak signal in the presence of strong signals, the autocorrelation peak of the weak signal must be stronger than the cross-correlation peaks from the strong signals. If the codes are orthogonal, the cross correlations will be zero. The Gold codes are not orthogonal but near orthogonal, implying that the cross correlations are not zero but have small values.

The two important correlation properties of the C/A codes can be written as fallows

1. **Nearly no cross-correlation** : All the C/A codes are nearly uncorrelated with each other.

The cross-correlation property can be written for *i* and *k* satellites.

$$r_{ik}(m) = \sum_{l=0}^{1022} C^i(l)C^k(l+m) \approx 0 \;\; for\; all\; m.$$

Where C^i and C^k is the C/A codes of satellites *i* and *k*

2. **Nearly no correlation except for zero lags**: All C/A are nearly uncorrelated with each other except Zero lag.

The Autocorrelation property can be written for kth satellite

$$r_{kk}(m) = \sum_{l=0}^{1022} C^k(l)C^k(l+m) \approx 0 \;\; for\;\; |m| \geq 1.$$

Where C^k is the C/A codes of satellites *k.*

This property makes easy to find out when two similar codes are perfectly aligned.

The correlation performs between 19th satellite and its delayed C/A code is shown below. The delayed signal generated randomly and it is started from 96 chip of original C/A code.

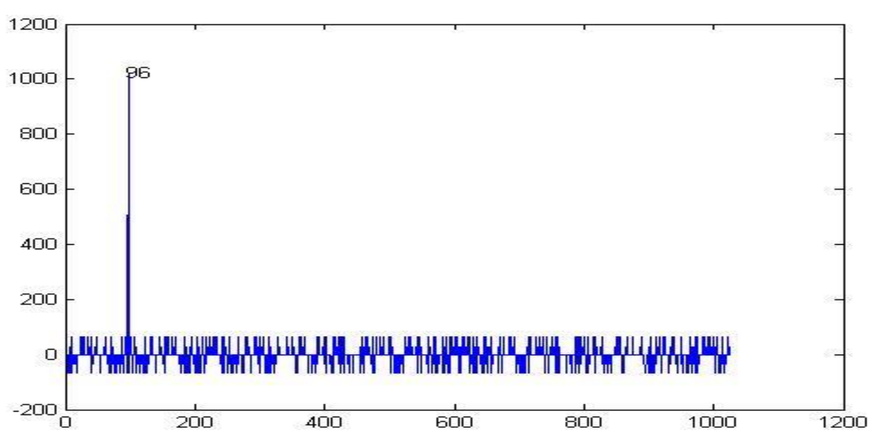

Figure 2.16: Auto-correlation of C/A code generation of 19th satellite and its delayed signal

The correlation performs between 19th satellite and 21st satellite of the C/A codes as fallows. When correlation performs between two different satellites the peak will not appear but it will have smaller values due to its correlation properties because of the gold codes are nearly orthogonal.

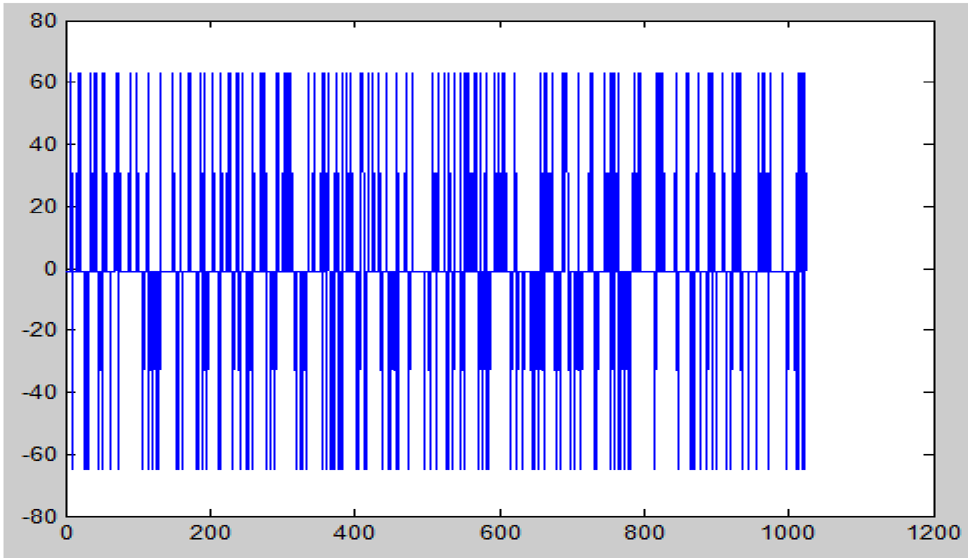

Figure 2.17: Cross-correlation of C/A code generation of 19th satellite and 21st satellite

2.5 Conclusion

This chapter explains about the Introduction of GPS architecture and principle operation of all segments and also discussed about GPS satellite signal structure, C/A code generation, correlation properties of C/A code. These are very useful to understand base band processing of GPS software receiver in next chapter.

3. GNSS Software Receiver

3.1 General overview of GNSS Receiver

Global Navigation Satellite System is a satellite-based navigation system that has been used widely both in civilian and military for positioning, navigation, timing and other position related applications. The hardware-based GNSS receivers provide less user flexibility, so it is necessary to have Software-based GNSS receivers for easy and quick implementation, simulation and analysis of algorithms. Software-based GNSS receiver processes the output of RF front end of GPS or GLONASS, which is at radio frequency or intermediate frequency that depends on the requirement of the receiver. In these software receivers different modules are available which will be introduced in this chapter.

3.2 Advantages of GNSS Software Receiver

A GNSS software receiver has more flexibility due to its hardware independence. The receiver is mainly implemented in software except for the front-end part, which offers various advantages. First, a software receiver removes the nonlinear, temperature-dependent components of conventional hardware receivers. Second, a software receiver can provide more evaluation and testing flexibilities. Some systems may collect complex data in both the in-phase (I) and Qudrature (Q) channels while others use real data from one channel.

The software receiver can also adapt to data digitized with various sampling frequencies. The performance of different algorithms can be compared without any hardware development. Third, it provides an effective simulation environment. New algorithms can be developed for the software receiver to solve problems, such as jamming signals, without altering the hardware components.

In order to properly calculate the user position, at least 30 seconds of GPS data is required. However, this is another advantage in a software receiver, where only 30seconds of data can be used to calculate an initial user position.

3.3 Basics of GNSS Receiver Architecture

A basic software-based GNSS receiver is composed of two main parts, as shown in Figure 3.1. The first part covers the hardware section, it can be divided in two functional blocks:

RF section and IF section. The RF section consists of analog hardware modules, responsible for RF to IF conversion, while the IF section is composed of digital hardware modules. The second part is the baseband software processing, which performs acquisition, tracking and Navigation decoding of the received signals, as well as the necessary algorithms used for the computations of the receiver PVT.

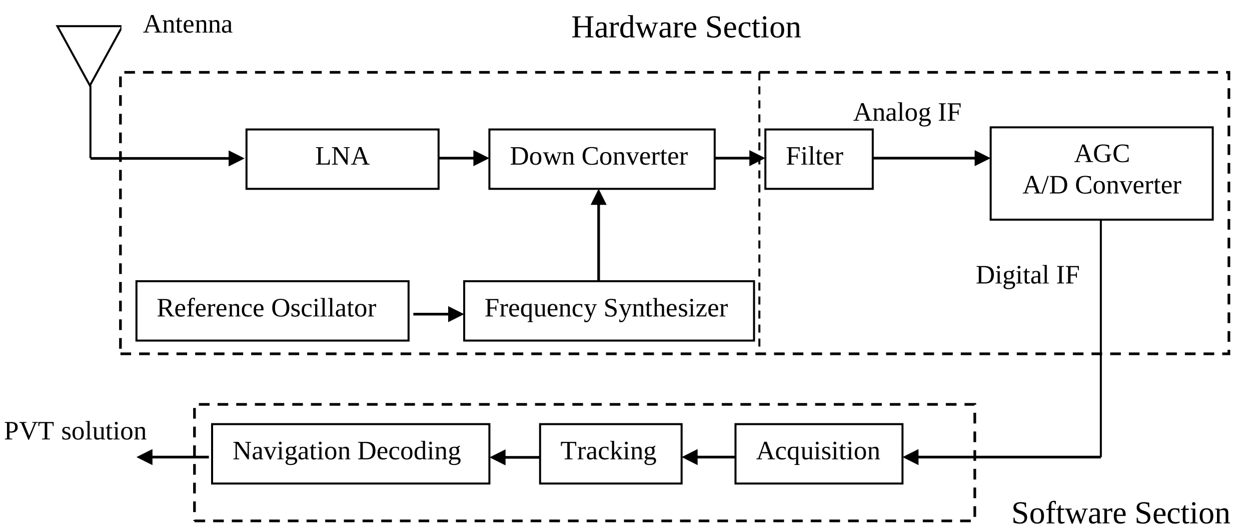

Figure 3.1: Basic software GNSS receiver

The operation of receivers section consists four blocks: antenna, RF front end, local oscillator, base band signal processing block. The antenna is first element of receiver architecture which will make the first signal conditioning. The transmitted signal from satellites is Right Hand Circularly Polarized (RHCP), so the antenna must be set to receive RHCP signals. The process starts with the signals transmitted from the satellites, propagating through space with the velocity of light, and incident on a GNSS's antenna. The antenna gain pattern is an important consideration that indicates how well the antenna performs at different centre frequencies, polarizations and elevation angles. Finally, all of the measurements on radio waves, time-delay measurements, phase measurements or doppler-shift measurements can be performed on the receiver side [2].

3.4 Base Band Processing

The base band processing mainly consists 3 blocks those are:

- Acquisition
- Tracking

- Navigation data decoding

3.4.1 Acquisition

Generally GNSS receiver must know which satellites are currently visible. There are two common ways of identify the initially visible satellites. One is referred to as warm start and the other is referred to as cold start. Similarly another way is hot start but it is same as warm start.

Warm start: In a warm start, the receiver combines information in the stored almanac data of the last position computed by the receiver. The almanac data is used to compute coarse positions of all satellites at the actual time. These positions are then combined with the receiver position in an algorithm computing which satellites should be visible. The warm start has at least two downsides. If the receiver has been moved far away since it was turned off (e.g., to another continent), the receiver position cannot be trusted and the found satellites do not match the actual visible satellites. Another case is that the almanac data can be outdated, so they cannot provide good satellite positions. In both cases, the receiver has to make a cold start.

Cold start: It takes longest time when the receiver does not depend on any stored information, so it starts from searching for satellites. The method of searching is referred to as acquisition, for the purpose of identifying the satellite signals [2].

3.4.2 Tracking

Once acquisition process completes, the acquisition gives rough estimation of the carrier frequency with Doppler and code phase offset parameters of all visible satellites of the receiver. These parameters fed into tracking part. The main purpose of tracking is to refine these values, keep track, and demodulate the navigation data from the specific satellite. In total satellites, visible satellites only required for tracking of satellites signals and other non visible satellites are not required. The estimated parameters from the acquisition of all visible satellites that are carrier frequency, code phase required to process tracking of a GPS L1 signal. In the tracking process of satellite signal, both carrier and code signal accurately reproduced inside the receiver, in this process frequency error (phase error) and code phase occurs, and these two parameters can be minimized to zero and produce an exact carrier wave to demodulate navigation data of satellite signal. To generate an exact carrier wave, two tracking loops are required. Code tracking loop generates exact code phase of incoming signal similarly frequency or phase locked loop generates exact carrier wave replica to demodulate navigation data. This navigation data is required to computing the position of satellites, receivers[2].

3.5 Navigation data decoding

The output from the tracking loop is the values of the in-phase arm of the tracking block truncated between the values 1 and −1. However in tracking part obtained a bit value for every ms. However, to deal with noisy and weak signals, so a mean value for 20 ms has to be computed. The navigation data of one bit duration equals to 20 ms, the bit rate of the navigation data is 50 bps. The sample rate of the output from the tracking block is 1000 sps (samples per second) corresponding to a value of each millisecond. Before the navigation data can be decoded, the signal from the tracking block must be converted from 1000 sps to 50 bps. That is, 20 consecutive values must be replaced by only 1. This conversion procedure can be called as bitsynchronization. The full description of navigation data decoding can be explained in next chapter [2].

3.6 Conclusion

This chapter explains about the general view of GNSS Software receiver and each unit of in this receiver has been discussed. However base band processing of software receiver consist acquisition, tracking and navigation data extraction which have been introduced and discussed a little bit amount to understand the acquisition and tracking algorithms in next chapter.

4. GPS C/A code Acquisition

4.1 Introduction

Generally GNSS receiver must know which satellites are currently visible. There are two common ways of identify the initially visible satellites. One is referred to as warm start and the other is referred to as cold start. Similarly another way is hot start but it is same as warm start.

Warm start: In a warm start, the receiver combines information in the stored almanac data of the last position computed by the receiver. The almanac data is used to compute coarse positions of all satellites at the actual time. These positions are then combined with the receiver position in an algorithm computing which satellites should be visible. The warm start has at least two downsides. If the receiver has been moved far away since it was turned off (e.g., to another continent), the receiver position cannot be trusted and the found satellites do not match the actual visible satellites. Another case is that the almanac data can be outdated, so they cannot provide good satellite positions. In either case, the receiver has to make a cold start.

Cold start: In a cold start, the receiver does not depend on any stored information. Instead it starts from searching for satellites. The method of searching is referred to as acquisition so that we are giving very high importance to acquisition because to identify satellite signals[2].

4.1.1 Significance of Acquisition

The general definition of acquisition is to identifying visible satellites to the user (Receiver). If any satellites are visible or available to receiver, then need acquisition and must determine the following properties of satellite generated signal. Those are:

(a) Frequency

Generally in GPS the satellite generated Carrier frequency (L1 band) is same for all Satellites. The frequency of the GLONASS signal from specific satellite is differing from its nominal value why because the satellite generated carrier frequency is vary for different satellites. In case of down conversion, the GPS carrier frequency is down converted to particular IF frequency and similarly the nominal frequency (zero channel frequency) of the GLONASS signal on L1 corresponds to the IF. However, the signals are affected by the relative motion of the satellite, causing Doppler Effect. The Doppler frequency shift can cause in the case of maximum velocity of the satellite combined with a very high user velocity leads to approach values as high as ±10 kHz of its nominal frequencies. Or a stationary receiver on Earth, the Doppler frequency shift will never exceed ±5 kHz.

(b) Code Phase

The code phase denotes the point in the current data block where the C/A code begins. It means the satellite generated PRN code (C/A code) and local generated C/A code matches. If a data block of 1ms is examined, the data include an entire C/A code and thus one beginning of a C/A code[2].

The purpose of acquisition is to identify all visible satellites to the user and determine coarse values of carrier frequency and code phase of satellites signals. In order to track and decode the information in the GPS and GLONASS signals, an acquisition method must be used to detect the presence of the signal. Once the signal is detected, the necessary parameters that are code phase and carrier frequency must be obtained and passed to a tracking program. From the tracking program information such as the navigation data can be obtained.

In GPS all satellites generates same carrier frequency (1575.42MHz) but each satellite having its unique PRN code, as well as in GLONASS system the satellites are separated by different carrier frequencies (1598MHz to 1605MHz) but having the same PRN code for all satellites. Why because the GLONASS system uses the FDMA (Frequency Division Multiple Access) technique but in GPS, each satellite is having different PRN code (C/A code) and having the same carrier frequency (1575.42MHz) for all satellites so that here we can say GPS uses the CDMA (Code Division Multiple Access).

To start the process of acquisition we need one data signal of GPS and GLONASS system, this data signal can be obtained from the RF front end, and this RF section consists one antenna that receives or collects the satellite generated signal The receiver received signal must be down converted to the intermediate frequency that corresponds to nominal frequency of satellite signal after amplification, then this IF signal is required to the process of acquisition. Because of received signal is having very high frequency, so that we need very high sampling frequency and also it leads to very complexity in the process of data so that we are converting

RF to IF to process easily in software receivers. Here the received signal frequency is not same as the frequency which is transmitted by the satellite. It means received signal frequency is equal to IF but it is shifted frequency having same information of original signal.

4.2 Introduction of Acquisition Methods

A variety of GNSS signal acquisition methods are presented in different references present the cell-by-cell search, the fast Fourier transformation (FFT), and the delay and multiplication method for GNSS signal acquisition. Each method has some advantages and disadvantages. For example, the delay and multiplication method is faster than FFT method but in case of weak signals, it has a lower performance. Therefore, there is a trade-off between speed and sensitivity. If the signal is strong, the fast-low sensitivity acquisition method can detect it but if the signal is weak, the FFT method is better able to find it. However, in case of weak signals, some other methods are presented. For the purpose of this work, only the cell - by - cell search method and FFT method are explained in next sections.

The Acquisition Process consist the following list

- Determine which satellites are visible to the antenna.
- Determine the approximate Doppler frequency of each satellite.
- Search for the signal in both C/A code phase and Frequency (i.e. Doppler Frequency).
- Detect a signal and determine its code phase and carrier frequency.

4.3 Acquisition Methods

This section of Acquisition methods describes the GNSS signal acquisition process for both conventional and software receiver architecture. Acquisition is a coarse synchronization process giving estimates of the PRN code offset and the carrier Doppler.

Most commonly used methods are:

In conventional hardware receivers

a) Serial search in time domain.

In software receiver approach

a) FFT method.

4.3.1 Cell – by – Cell search method

In the cell-by-cell search method, GNSS signal acquisition is a two dimensional search process in which a replica code and carrier are aligned with the received signal. In the two dimensional search process the x- axis represents the code phase and the y-axis represents the Doppler Frequency bin, when both frequency and code phase are aligned, then the correct alignment is identified by measurement of the output power of the correlators.

The two dimensional array of cells shown in figure 4.1, is a representation of acquisition search space consisting of all combinations of code delay and frequency used in the acquisition search space.

In the cell – by – cell search method, the correlation is performed in the time domain, where the locally generated ranging code is shifted and accumulated for all possible shifts. Therefore, for GNSS signal acquisition, all C/A ranging code chips are examined. Typically, code chip is searched in increments of half chip and each code phase value to be searched is considered a code bin. This process is repeated for all Doppler bins. In fact, the entire range of Doppler frequency search is divided into smaller cells called Doppler bin. One code bin and one Doppler bin create a cell. The search starts from a particular code bin and particular frequency bin. If the signal is not detected, another code bin is examined. It continues until all code bins for that particular frequency bin are exhausted. Then, the search continues on the adjacent frequency bins and for all code bins until all the cells are examined or the signal is detected [5].

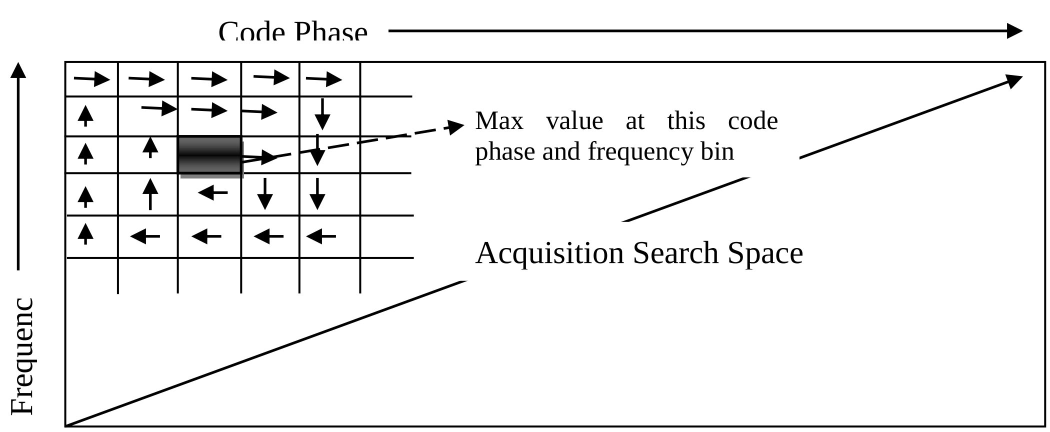

Figure 4.1: Cell – by – Cell Search Diagram

In cell – by – cell search method, it searches all possible frequency bin and code phase, each frequency and code phase will create one cell similarly all cells have formed and then it searches all cells of combinations and takes the maximum value in the row of first frequency bin and all code phase samples, this value is stored in one table, then after completion of search in all frequency bins, codephase result of all maximum values are stored, in that result table we will take maximum of maximum values, here the code phase value has been determined, it means this code phase value is having highest peak value around this peak value exclude the samples and find the second peak value using excluded samples after find the ratio of first and second peak value the resulting value will exceed the defined threshold value then the satellite detection is founded. Thus the acquisition search space by cell – by – cell method can be done [5].

The acquisition method must search over a frequency range of ±7 kHz (in our case) to cover all of the expected Doppler frequency range for high-speed aircraft. In order to achieve the acquisition space search in a short time, the bandwidth (frequency step) of the searching program cannot be very narrow. Using a narrow bandwidth for searching means taking many steps to cover the desired frequency range and it is time consuming. Searching through with a wide bandwidth filter will provide relatively poor sensitivity.

Similarly there are several different standard methods to perform acquisition. The most commonly used methods are:

1. Serial search in time domain
2. Parallel search in frequency domain or FFT method
    a. Parallel frequency space search acquisition.
    b. Parallel code phase search acquisition.

Though serial search is the slowest search method, it is usually implemented in hardware based receivers due to its simplicity and low cost. The parallel search (FFT method) in frequency domain usually implemented by software receiver since serial search method is computation intensive in the software approach.

4.3.2 Serial Search in Time Domain

The purpose of acquisition is to identify all visible satellites to the user and determine coarse values of carrier frequency and code phase of satellites generated signals. The code phase is the time alignment of the PRN code (C/A code) in the current block of data (1ms of processed data). It is necessary to know the code phase to generate a local PRN code that is perfectly aligned with the incoming signal containing PRN code because this is the only way to remove the incoming code. Another parameter is the carrier frequency, which in case of down conversion corresponds to IF. The frequency can be different because of the Doppler Effect. In most cases it is sufficient to search the frequencies such that the maximum frequency error will be less than or equal to 100Hz or 500Hz depending upon our requirement [2].

Serial search is the simplest and most frequently used acquisition method especially in hardware GNSS receivers. This method uses cell-by cell search technique. In this algorithm digital IF or incoming signal is multiplied by locally generated PRN code sequence (C/A code) and locally generated carrier signals. The local C/A code generator generates 32 C/A codes for all satellites in GPS system. But in GLONASS the local C/A code generator generates a same C/A codes for all GLONASS satellites. The generated sequence has a certain code phase, from 0 to 1023 chips for GPS and 0 to 511 chips for GLONASS. When it is sampled with a sampling frequency of 4.7MHz in GPS and 16MHz in GLONASS, then length 'L' of one C/A code becomes 4774 samples in GPS and similarly 16000 samples in GLONASS. Here each sample takes 1 kHz frequency resolution for both GPS and GLONASS.

After multiplication with the generated PRN sequence, the C/A code can be despread remaining signal consist only carrier signal with Doppler frequency. In the next phase remaining signal is multiplied by a local oscillator generated carrier signals that are inphase (I) and Qudrature (Q) signals. In-phase signal (I) is having 0° phase , and Qudrature signal is having 90° phase-shifted version of the locally generated carrier signal [2].

These I and *Q* signals are integrated over 1ms, corresponding to the length of one C/A code (1ms = 4774 samples (GPS) or 16000 samples (GLONASS)), and finally squared and added. Ideally, the signal power should be located in I^{th} part of the signal; because C/A code is only modulated onto that but this does not always happen because the phase of the received signal is unknown.

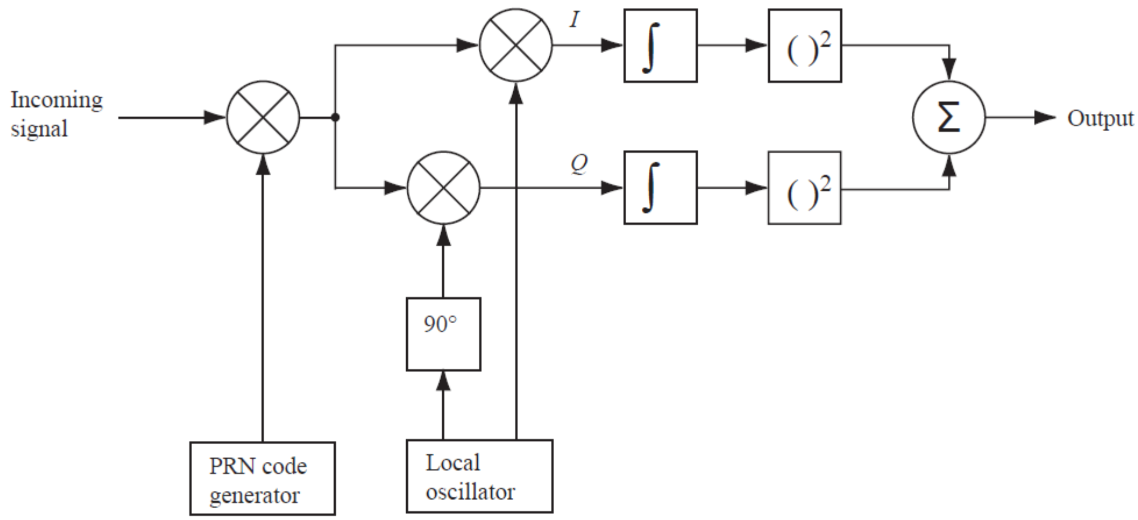

Figure 4.2: Serial Search Algorithm

The output is a value of correlation between the incoming signal (digital IF) and the locally generated signal. To remove the ranging code from the incoming signal, correlation is required. If the output exceeds a predefined threshold value, the frequency and code phase parameters are correct, and these parameters can be passed on to the tracking algorithms.

The serial search in time domain algorithm performs two different sweeps:

1. Frequency sweeps over all possible carrier frequencies of IF ±7 kHz(in our case Doppler frequency is set to ± 7kHz) in steps of 500 Hz
2. Code phase sweep over all 1023 or 511different code phases. All in all, this sums up to a total of

   For GPS

$$1023\left(2\times\frac{7000}{500}+1\right) \qquad = 1023\times 29 = 29667 \text{ combinations}$$

   For GLONASS

$$\underbrace{511}\ \underbrace{\left(2\times\frac{7000}{500}+\ 1\right)} \qquad = 511\times 29 = 14819 \text{ combinations}$$

Where 1023 and 511 represents code phase, remaining are represents frequencies

Obviously, this is a very large number of combinations. This exhausting search routine also tends to be the main weakness of the serial search acquisition.

Usually when serial search is performed the code phase is incremented by 1/2 chip when one code phase has been tested. Therefore, for GPS there are 2×1023=2046 and similarly for GLONASS 2×511 = 1022 code phases that must be searched. In the software receiver implementation, with the input signal is sampled at 4.7MHz for GPS and 16MHz for GLONASS, so 9,548 and 32,000 samples of the received data are correlated with the locally generated C/A code by sliding the replicated code over the 9,548 and 32,000 samples respectively. Figure illustrates the linear search over the range of possible carrier frequencies.

The frequency resolution obtained from the 1ms of data is about 1 kHz; the frequency resolution is determined by the coherent integration time (or dwell time) [1]. The relation is

$$D = \frac{2}{3T}$$

Where D is the frequency bin width in Hz

T is the predetection integration time in seconds.

By stripping the C/A code from the input data, the remaining signal becomes a continuous wave. Once the input signal becomes a continuous signal, fast Fourier transform (FFT) can be used to find the frequency, and this operation is referred to as coherent integration. It performs and process only 1ms of input data.

Typically a set of long input data is divided into many blocks and coherent integration is performed on all the blocks. After the coherent integration every frequency output is complex and can be put into amplitude form. The amplitudes from the all coherent integration of the same frequency are summed. Non coherent integration uses the outputs of coherent integration.

(a) PRN Sequence Generation

The main task in any GNSS acquisition method is to multiply the incoming signal with the locally generated PRN sequence. The PRN (Pseudo Random Noise) code is a series of bits which are produced using a two feedback shift registers G_1 and G_2, this code repeats itself for every millisecond, it is produced using the two polynomial equations i.e. $G_1: 1 + x^3 + x^{10}$ and $G_2: 1 + x^2 + x^3 + x^6 + x^8 + x^9 + x^{10}$. G_1 and G_2 are generated by a maximum-length linear shift register of 10 stages and are operated by a 1.023 MHz clock

Similarly in GLONASS acquisition method to multiply the incoming signal with the locally generated PRN sequence. The PRN (Pseudo Random Noise) code is a series of bits which are produced using a shift register, this code repeats itself for every millisecond, it is produced using the polynomial equation $1+ x^2 + x^5$ and in the GLONASS case the C/A code is having a period of 511 chips which are repeated. GLONASS ranging code is not a Gold code but is a maximum length 9-stage shift register sequence.

The first task in the serial search acquisition method is to multiply the incoming signal with the locally generated PRN sequences of all satellites. Instead of generating PRN sequences every time the algorithm is executed, all possible PRN sequences are generated offline. The 32(GPS), 14(GLONASS) PRN sequences are generated by the PRN generator.

The PRN code generator is implemented using the binary values -1 and 1. However, in the signal processing algorithms it is more convenient to represent the codes with a polar non-return-to-zero representation. With generated all satellites PRN sequences, all possible sequences originating from GPS and GLONASS satellites are created. The method involves multiplication with all possible shifted versions of the PRN codes.

(b) Carrier Wave Generation

The second step in acquisition is multiplication with a locally generated carrier wave. The satellite generated signal consists the Carrier, C/A code and Data, the same Carrier can be generated locally at the GNSS Receiver using local oscillator because to remove the carrier in the GNSS signal.

In GPS systems all satellites generates same carrier frequency that is in the range of 1575.42MHz and it has down converted to some intermediate frequency 1.193 MHz and it is being sampled with sampling frequency of 4.7MHz.

(c) Integration and Squaring

The last end parts of the serial search algorithm involve integration and squaring of the two results of the multiplications with the cosine and sine signals, respectively. The squaring is introduced to obtain the signal power. The integration is simply a summation of all 4774 (GPS), 16000 (GLONASS) points corresponding to the length of the processed data (1ms). It is also acts as low pass filter, it eliminates high frequency components. The squaring is then performed on the result of the summation. The final step is to add the two values from the *I* arm and the *Q* arm.

If the locally generated code is well aligned with the code of the incoming signal, and the frequency of the locally generated carrier matches the frequency of the incoming signal, the output will be significantly higher than if any of these criteria were not fulfilled [2].

At last we can conclude serial search algorithm is not useful in software receiver approach, this can be used in conventional hardware receivers (ASIC) due to its low cost and complexity. However serial search method is mostly used in commercial receivers because of its simple implementation.

4.3.3 Parallel Search in Frequency Domain

The serial search acquisition method showed that it is a very time-consuming procedure to search sequentially through all possible values of the two parameters carrier with Doppler frequency and code phase. If any of the two parameters could be eliminated from the search procedure or if possible implemented in parallel, the performance of this procedure would increase significantly.

This second method of acquisition parallelizes the search for the one parameter. This method utilizes the Fourier transform to perform a transformation from the time domain into the frequency domain. This is also called FFT search method [3].

There are two standard methods in this parallel search acquisition method:

- Parallel frequency space search acquisition
- Parallel code phase search acquisition

4.3.3.1 Parallel Frequency Space Search Acquisition

The second method of acquisition parallelizing the search for the frequency, named *Parallel Frequency Space Search*. Initially this method is identical to the *serial search method*. This second method of acquisition parallelizes the search for the one parameter and it utilizes the Fourier transform to perform a transformation from the time domain into the frequency domain.

In the parallel acquisition process, the digital IF (incoming signal) is multiplied by a locally generated PRN sequence, with a code corresponding to satellite and a code phase having 0 to 1023 chips for GPS and 0 to 511 chips for GLONASS, after the code multiplication, resulting signal is transformed into the frequency domain through a Fourier transform. The Fourier transform could be implemented as a Discrete Fourier Transform (DFT) or a Fast Fourier Transform (FFT). In this algorithm with a perfectly aligned PRN code (C/A code), the output of Fourier transform will show a distinct peak in magnitude corresponding to the frequency of carrier signal. This peak will be located at the frequency index to corresponding frequency of the carrier wave signal.

The accuracy of the frequency depends on length of the DFT or the number of samples in data can be analyzed. The FFT is the faster of the two; but it requires an input sequence with a radix-2 length, that is, 2^n, where n takes positive integer value. The output of FFT will have a peak at IF plus Doppler offset frequency. The absolute values of all components are calculated in order to determine the frequency of a possible peak[3].

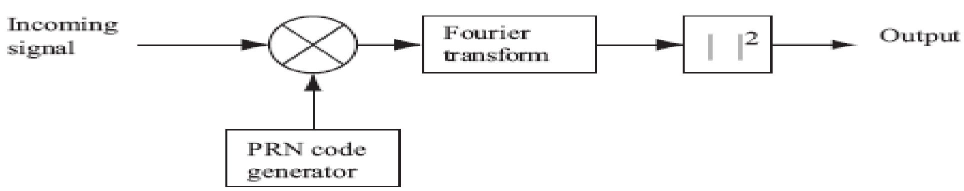

Figure 4.3: Parallel frequency space search algorithm

The above block diagram illustrates the result of multiplying the incoming signal with a perfectly aligned C/A code of locally generated PRN sequence then the result becomes a continuous wave signal. This happens only when the locally generated PRN code is perfectly aligned with the code of incoming signal. If the incoming signal contains signal components from other satellites, these components will be minimized as a result of the cross-correlation properties of the PRN sequences.

The accuracy of the determined frequency depends on the length of the DFT. The length corresponds to the number of samples in the analyzed data, with the parallel frequency search acquisition method only steps through the 1023 and 511 different code phases for GPS and GLONASS respectively. Depending the implementation in frequency domain transform it should possible to make a faster implementation of this method compared to the serial search method. If 1ms of data is analyzed, the number of samples can be found as $\frac{1}{1000}$ of the sampling frequency. That is, if the sampling frequency is F_s = 4.7MHz (GPS), 16 MHz (GLONASS), the number of samples is N = 4774 and 16000.

With a DFT length of N, the first *N/*2 output samples represent the frequencies from 0 to $\frac{F_S}{2}$ Hz. That is, the frequency resolution of the output is

$$\Delta f = \frac{F_S/2}{N/2} = \frac{F_S}{N}$$

With a sampling frequency of F_S = 16 MHz, 4.7 MHz the resulting frequency resolution is

$$\Delta f = \frac{16\text{MHz}}{16000} = 1 \text{ kHz} \qquad \Delta f = \frac{4.7\text{MHz}}{4774} = 1 \text{ kHz}$$

In this case, the accuracy of the estimated carrier frequency is 1 kHz compared to the accuracy of 500 Hz in serial search acquisition. Where the serial search acquisition method steps through possible code phases and carrier frequencies, the parallel frequency space search acquisition only steps through the 1023 and 511 different code phases for GPS and GLONASS respectively. Depending on the implementation of the frequency domain transformation, it should be possible to make a faster implementation of this method compared to the serial search acquisition method.

This method depends on the realization of the frequency domain transform. It is possible to find a way to make it faster than the serial search acquisition method. The specifically important fact is that the accuracy of the carrier frequency can be further improved by increasing the length of the DFT [4].

The implementation of the parallel frequency space search method is same as the serial search acquisition method. The algorithm can be implemented directly based on the block diagram shown in Figure. Initially the locally generated PRN code must be multiplied with the incoming signal. After the code multiplication, the signal is transformed into the frequency domain through Fourier transform. An efficient tool for that is the fast Fourier transform (FFT).

After transforming the signal into the frequency domain by means of the FFT algorithm, it becomes a complex signal. If the locally generated code is well aligned with the code in the incoming signal, the output from the FFT will have a peak at the IF plus Doppler offset frequency. The absolute values of all components are calculated in order to determine maximum value of peak and its frequency of possible peak [5].

The following method of Parallel frequency space search eliminating the necessity of searching through the 29 possible frequencies. The goal of the Parallel Code Phase Search Acquisition is to parallelizing the code phase.

The parallel frequency search method eliminates the search through the possible different Doppler frequencies, generally this algorithm is used to fine carrier frequency resolution to estimate carrier frequency of incoming signal it is possible only when the estimated codephase available from coarse acquisition by using parallel code phase search method.

4.3.3.2 Parallel Code Phase Search Acquisition

Another recent and standard method of acquisition is parallelizing the codephase search, so it as named *Parallel code phase Search*. Initially this method is identical to the *serial search method*. The previous second method of acquisition parallelizes the search for one parameter i.e. frequency and then utilizes the Fourier transform to perform a transformation from the time domain into the frequency domain

The main goal of acquisition is to perform a correlation with an incoming signal and a PRN code. The goal of this technique is to parallelize the code phase search. Thus a parallelization of the code phase search will greatly reduce acquisition times; even beyond what can be obtained using the previous methods which are parallelizes the frequency search, serial search acquisition. The amount of search steps in the code phase dimension is significantly larger than that in frequency (Instead of using 511codpases here using only 29 frequencies). It means when the code phase is implemented in parallel only 29 steps of frequencies are required.

The previous method parallelized the frequency space search, serial search acquisition eliminating the necessity of searching through 29 possible frequencies when the frequency width 500Hz is taken. If the acquisition could be parallelized in the code phase dimension, only 29 steps should be performed compared to the 511 in the parallel frequency space search acquisition algorithm. This method is simply referred to as parallel code phase search acquisition.

In the parallel code phase search acquisition, primarily the incoming signal is multiplied with a generated cosine and sine carrier wave from the local oscillator, obtaining an Inphase (I) and a Qudrature (Q) signal to be used as a real and imaginary, these two are combined as a complex input to the Fast Fourier transform or DFT function. The result is multiplied by the DFT of complex conjugate of a complex number who's real and imaginary components are equated to the complete PRN code.

After multiplication of DFT result and complex conjugate of PRN code, resulting sequence is taken into input to IDFT; it will transform from frequency domain to time domain and find the magnitude of the resulting sequence is the circular correlation of the two sequences.

This result is very similar to that obtained using the serial search. The maximum value of the resulting sequence corresponds to the best estimate of the code phase of that PRN sequence in the data set (1ms) for the frequency bin index tested. If that maximum value exceeds a predetermined threshold, a peak is present in the correlation, the index of this peak marks the PRN code phase of the incoming signal. If that maximum value does not exceed the predetermined threshold, either the collected data does not contain a signal utilizing that PRN code and/or the frequency evaluated is incorrect The remaining potential parameters, PRN codes and frequencies, can be cycled through until acquisition is successful [5].

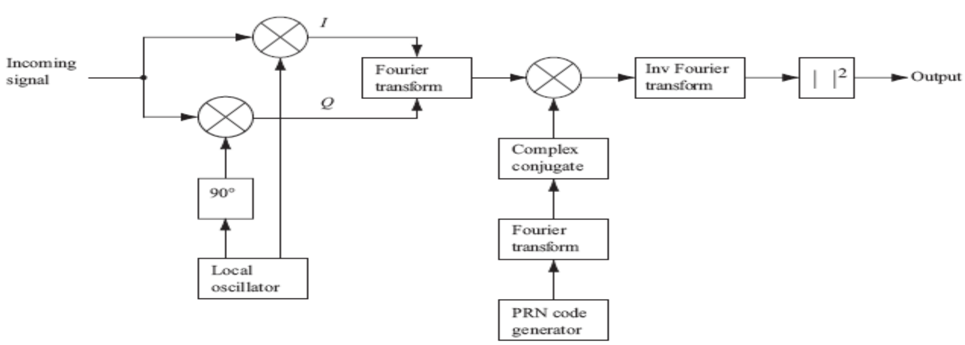

Figure 4.4: Parallel code phase search algorithm

Comparing all the previous acquisition methods, the parallel code phase search acquisition method has cut down the search space to only 29 possible different carrier Doppler frequencies. For each satellite acquisition, the Fourier transform of the generated PRN code must be performed once. For each of satellite 29 frequencies should perform one Fourier transform and one inverse Fourier transform, so the computational efficiency or performance depends on the implementation of these functions [1][2].

Table 4.1: Comparison of Acquisition algorithms

Algorithm	Repetitions	Complexity
Serial Search	14819	High
Parallel Frequency Search	511	Medium
Parallel Codephase Search	29	Low

(1) Compared with serial acquisition method, the FFT based method changes two-dimension search of code delay and Doppler shift to one-dimension search, improves the acquisition speed greatly.

(2) FFT-based acquisition method avoids sophisticated hardware cost by only software modification and little hardware modification and with good flexibility.

(3) FFT algorithm is applicable for high speed digital signal processor and can meet real-time and accuracy demand of full digital receiver.

The FFT search algorithm is used in MATLAB implementation because of its significant fast acquisition speed compared to serial search method.

The accuracy of estimated parameters by this acquisition method, the PRN code phase, however, it is more accurate compared to the other methods as it gives a correlation value for each sampled code phase. That is, if sampling frequency is 4.7 MHz and 16MHz for GPS and GLONASS, a sampled PRN code has 4,774 and 16,000 samples in 1ms. In the same way as with the other acquisition methods, the implementation of this one is straightforward, as it can be implemented directly based on the block diagram shown in figure4.7.

(a) Acquisition using Circular correlation

The acquisition program of the software receiver uses the circular correlation method to find the signal. Only 1ms of input data is used to obtain the beginning of the C/A code initially. Since the sampling frequency of the signal is F_s, there are N samples in one C/A code period of duration one millisecond. Since the C/A code does not necessarily start at the beginning of the input data, the beginning of the C/A code needs to be found before dispreading the data. A local copy of the specific C/A code is generated for 1ms and digitized at a frequency of 4.7MHz (GPS), 16 MHz (GLONASS) to create the 4,774 and 16,000 samples needed. The digitized code is then slid over the 4,774 and 16,000 sample input data to find the peak correlation value [5].

The parallel code phase search algorithm can be implemented using circular correlation. The circular correlation is a multiplication in the frequency domain that can be expressed as.

$$R[m] = \underbrace{x(n) \otimes CA[-n]}_{\text{Circular correlation}} = F^{-1}(F(x[n]).F(CA[n]^{*}))$$

The circular correlation used in Parallel code phase search acquisition method is more suitable for software approach. However the input data is used here only 1ms of data to find beginning point of C/A code with the searching frequency resolution is 1 kHz.

Where the fast Fourier transforms (FFT) and its inverse (IFFT) is used to calculate *R*. Since the fast Fourier transform is used to implement the DFT and IDFT, the acquisition is also called the FFT search.

If the input data length is 1 ms long, the FFT will have a frequency resolution of 1 kHz. A threshold needs to be set to determine if the frequency component is strong enough. The highest frequency above the threshold is the desired frequency component. Since the GLONASS signal is digitized at 16 MHz, and GPS signal is digitized at 4.7MHz. In the case of GLONASS 1ms of data contains 16,000 data points, so a 16,000-point FFT contains 16,000 frequency components. However, only the first 8,000 points of the FFT contains useful information. The second half of the frequency components is the complex conjugate of the first half. Since the frequency resolution is 1 kHz, the total frequency range covered by the FFT is 8 MHz, which is half of the sampling frequency. Similarly GPS follows the same procedure but here only 2387 point of the FFT contains useful information.

(b) Fine Carrier Frequency Resolution

To find the carrier frequency with finer resolution, the FFT is no longer an efficient method. To obtain 100 Hz frequency resolution with FFT, the data length required is 10ms.With the sampling rate of 4.7MHz (GPS), 16 MHz (GLONASS), and a total of

4, 77,400$\left(4774000 \times \frac{10}{1000}\right)$ for GPS

1, 60,000 $\left(16000000 \times \frac{10}{1000}\right)$ for GLONASS points FFT have to be computed.

Similarly to obtain 10Hz frequency resolution with FFT, the data length required is 100ms, which is a time consuming operation.

From the Code phase search algorithm we obtained beginning of a C/A code using this C/A code is stripped of from the input signal, the input becomes continuous signal. In fine frequency resolution, The Fourier transform can be implemented by DFT or FFT. The latter is faster but always requires the input sequence with a length of 2^n, where n is a positive integer the FFT algorithm cannot be applied directly. The most often used method is to add 0's to the input sequence. This method does not affect Fourier transform result of sequence and only causes changes of frequency samples' positions. However in some cases, it reduces the efficiency of the FFT and makes it impossible to get the DFT values on certain frequency samples if required.

After applying FFT to obtained continuous signal, the result gives highest power of frequency index value; it represents obtained estimated carrier frequency. The final estimated carrier frequency is calculated using its phase relationship. The initial carrier frequency is estimated to be the highest frequency component of the FFT. Let the highest frequency at time m be represented as $X_m(k)$, where k is the k^{th} frequency component calculated in the FFT [4][5].

The initial phase $\Theta_m(k)$ can be calculated using the real and imaginary components of $X_m(k)$ as

$$\Theta_m(k) = \tan^{-1}\left(\frac{Im(Xm\ (k))}{Re(Xm\ (k))}\right)$$

4.4 Algorithm Implementation

The proposed frequency domain parallel acquisition method can be performed by the following two steps[3]:

The first step is the coarse acquisition, which utilities the parallel code phase acquisition method. It is in steps of 1 kHz over possible frequencies of intermediate frequency IF±7kHz. In coarse acquisition it requires two DFT, one N point complex multiplications and one IDFT. After performing the frequency domain correlation in which the DFT is implemented by mixed-radix FFT, the accurate C/A-code phase is obtained and the carrier frequency is found with 1 kHz resolution which is too coarse for further signal tracking. If the ratio of the first two maximum peaks after the frequency domain correlation is above the preset threshold, enter fine acquisition to look for the more accurate carrier frequency; otherwise return to the beginning of the acquisition.

The next step is the fine acquisition, which utilities the parallel frequency space acquisition method. Based on the accurate estimated code phase from previous coarse acquisition step, the continuous signal can be obtained by stripping the C/A-code from the incoming signal. The more accurate estimated carrier frequency is got via a FFT approach as well as increasing the length of the FFT.

4.4.1 Coarse Acquisition

a) Perform the DFT on the locally generated C/A-code $c\ (n)$ to convert it into frequency domain as $C\ (k)$. Take the complex conjugate $C\ (k)$ and the output becomes $C^*\ (k)$.

b) Generate the local carrier signal $s_{Ii}\ (n)$ and its 90°phase-shifted version $s_{Qi}\ (n)$.

c) Multiply the 1ms incoming signal $x_1(n)$ by $s_{Ii}\ (n)$ and $s_{Qi}\ (n)$ respectively, giving an I and a Q signal component. The combination of these two generates a complex input to the DFT function and calls the acquisition result 1 $X_{1i}\ (k)$. Do the same operation on the following 1ms incoming signal $x_2(n)$ and call the acquisition result2 $X_{2i}\ (k)$.

d) Multiply $X_{1i}\ (k)$ and $X_{2i}\ (k)$ by $C^*\ (k)$ respectively and call the results $R_{1i}\ (k)$ and $R_{2i}\ (k)$;

e) Take the inverse DFT of $R_{1i}\ (k)$ and $R_{2i}\ (k)$ to transform the results into time domain and find the absolute values as $|r_{1i}\ (k)|$ and $|r_{2i}\ (k)|$, among which take the one where the maximum correlation peak is as the correlation result $|r_{1i}\ (k)|$ and record it;

f) If all the frequency bins are tested, we get $r(n)$ composed of all $|r_i(k)|$ s with different frequency bins and then go to step g, otherwise go to step b;

g) The maximum of $r(n)$ is the desired result, if the ratio of the first two maximums of $r(n)$ is above the preset threshold. The C/A-code phase T is marked corresponding to the index of the peak [5].

4.4.2 Fine Frequency Acquisition

a) Strip the C/A-code from the 10ms incoming signal using the estimated C/A-code phase from previous coarse acquisition and then obtain the 10ms continuous signal as $x\,c(n)$;

b) Find the positive integer n satisfying the inequality $2^n \geq length(k.x\,c(n))$ and take $M = 2^n$ as the length of the FFT, where k is a positive integer;

c) Take the M -point FFT of $x\,c(n)$ to transform it into frequency domain and find the absolute value as $|XC(k)|$;

d) Find the maximum of $|X\,C(k)|$ and calculate the refined carrier frequency according to the index of the peak [5].

4.5 Acquisition Results

Acquired satellites signals from Acquisition search algorithm (FFT Method)

From the FFT method of acquisition acquired satellites (visible satellites), not acquired satellites, their peak values as shown in below figure via histogram representation.

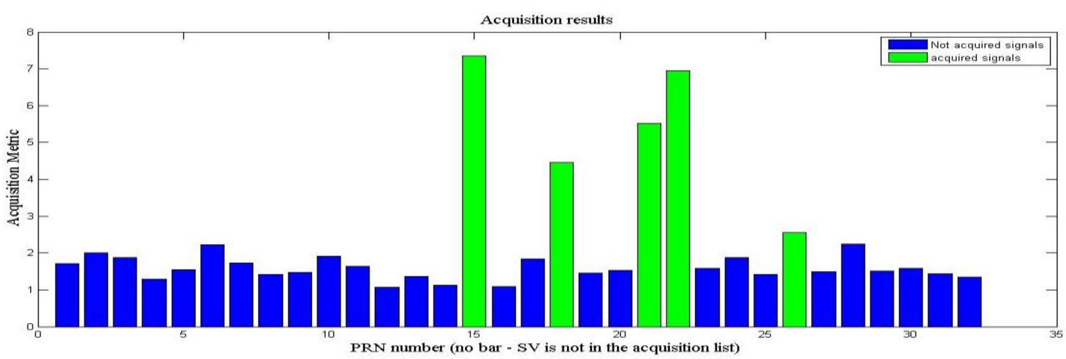

Figure 4.5: Histogram representation of all satellites

4.5.1 Observations of Acquisition algorithm

To verify acquisition program works properly, first it uses 1ms of incoming signal (data block of 1ms) similarly it takes another 1ms of incoming signal, these two signals of 1ms duration performs correlation with a locally generated C/A code signal to estimate beginning point of codephase value of acquisition search satellites.

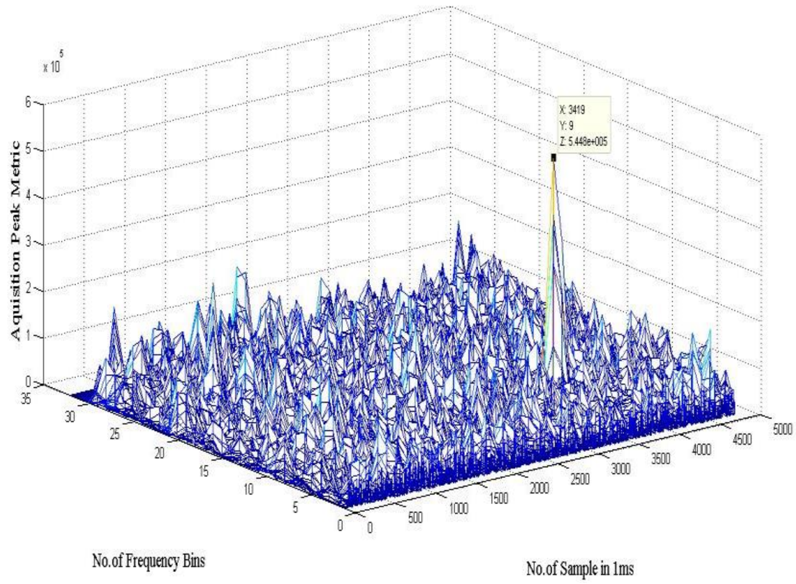

Figure 4.6: Acquisition of Satellite 26 at IF with Doppler frequency bin number 9

Above Figure illustrates the result of acquisition process for simulated GPS signal satellite (PRN) 26, where the peak represents estimated beginning point of C/A code and carrier frequency of satellite 26 calculated by the acquisition program.

In the 4774 point sampled input data of 1ms duration, the peak value of satellite 26 occurs at sample of 3419 means at this point, Hence the incoming signal and local generated C/A code signal matches, also frequency of that satellite matches at

$$(\text{IF} - \frac{14}{2} \times 1000 + 0.5\ \text{kHz} \times (9 - 1) = 1.190\text{MHz}$$

Where IF = 1.193MHz (9.548MHz/8)

Above frequency (1.190MHz) value consist highest frequency component, the correlation peak at this frequency component having much greater than acquisition threshold value. So that it is the estimated carrier frequency with Doppler shifts of satellite.

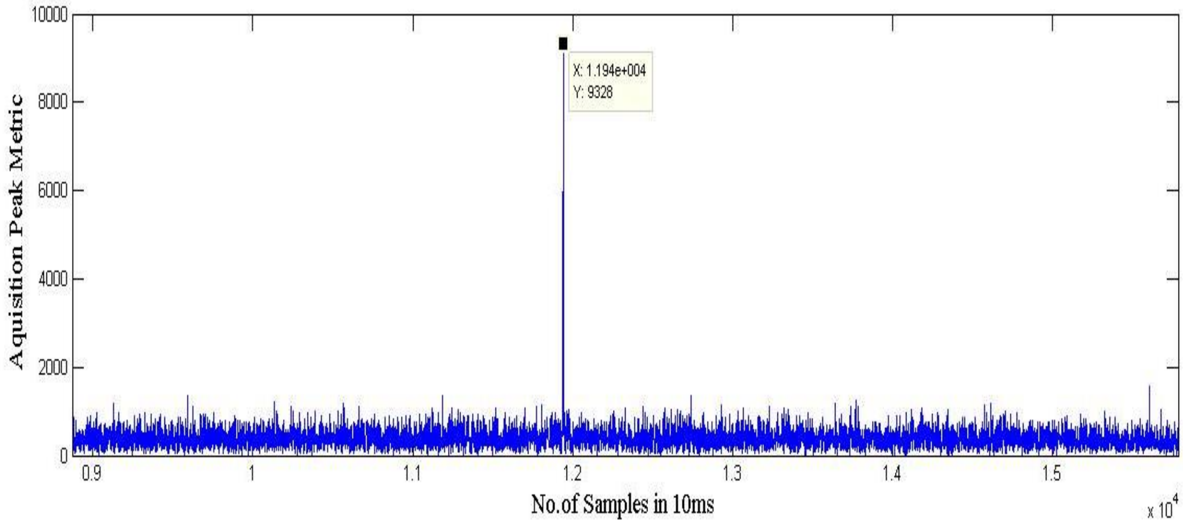

Figure 4.7: Acquisition of satellite at IF 1.194MHz

In the above figure 10ms of samples consisting 47740 samples each sample is having 100Hz frequency resolution; it can be obtained from parallel frequency search acquisition to estimate the carrier frequency of particular satellite from estimated codephase value of coarse acquisition.

From the results, it can be verified that the Doppler shift did not cause the ideal carrier frequency to shift much. The initial estimated carrier frequency is still 1.194MHz; however the final carrier frequency output of the acquisition program is 1.193737MHz this value is obtained after several frequencies refined searches. Since the initial frequency resolution is 1 kHz, the estimated carrier frequency will be too coarse for the tracking program. The bandwidths of the tracking loops are very narrow, so the final estimated carrier frequency should be within a few Hertz of the actual carrier frequency.

Similarly all obtained satellites of estimated code phase offset and carrier frequency with Doppler is shown in below figures. In the process of coarse acquisition, initial frequency resolution was taken as 1 kHz, but in the process of fine frequency resolution initial frequency resolution was taken as 100Hz.

Output from parallel codephase and parallel frequency search acquisition, satellite PRN 26 is visible so a significant peak is present. The peak occurs at C/A code phase = 1741chips and Doppler frequency bin number of 24.

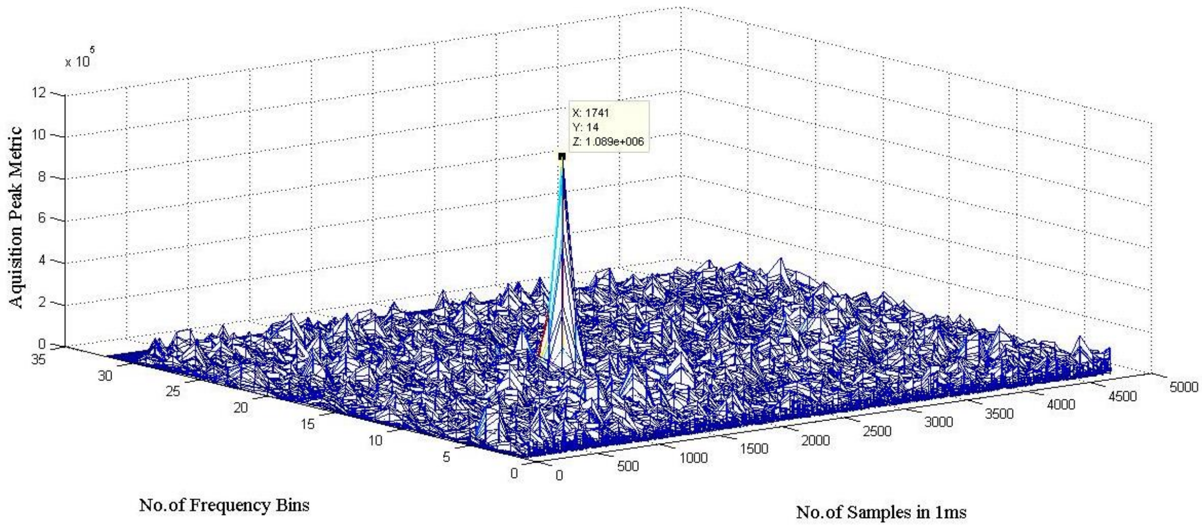

Figure 4.8: Acquisition of satellite 21 at IF with Doppler frequency bin number 14

In the 4774 point sampled input data of 1ms, the beginning of the C/A code is calculated to be at sample 1741. The correlation peak at this sample value is much greater than the predetermine threshold value.

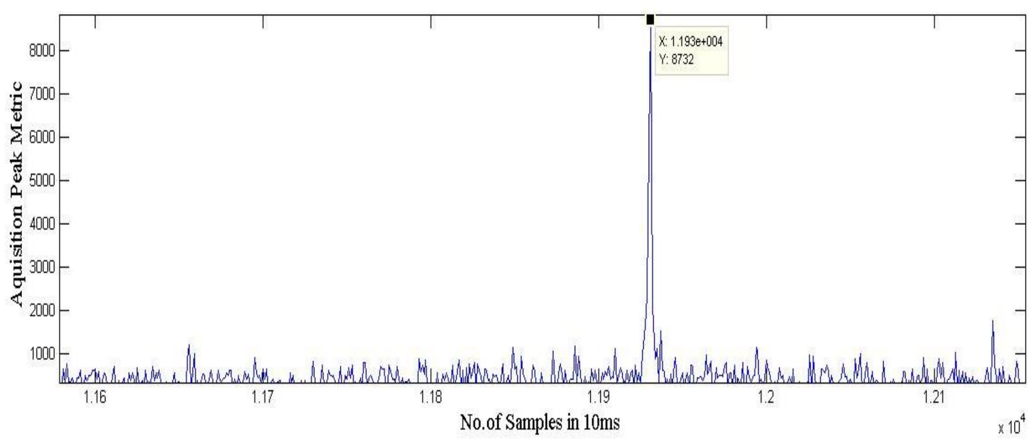

Figure 4.9: Acquisition of Satellite 21 at IF 1.193MHz

From the above figure, it can be verified that the Doppler shift did not cause the ideal carrier frequency to shift much. The initial estimated carrier frequency is still 1.193MHz; however the final carrier frequency output of the acquisition program is 1.192926MHz this value is obtained after several frequencies refined searches from parallel frequency space search algorithm. Since the initial frequency resolution is 1 kHz in parallel code phase search acquisition, for this frequency resolution the estimated carrier frequency will be too coarse for the tracking program. The bandwidths of the tracking loops are very narrow, so the final estimated carrier frequency should be within a few Hertz of the actual carrier frequency. Similarly for all visible satellites of carrier frequency can be estimated from estimated codephase value of coarse acquisition algorithm, can remove C/A code from incoming signal, hence remaining signal consisting only carrier frequency of particular satellite PRN with a less frequency resolution.

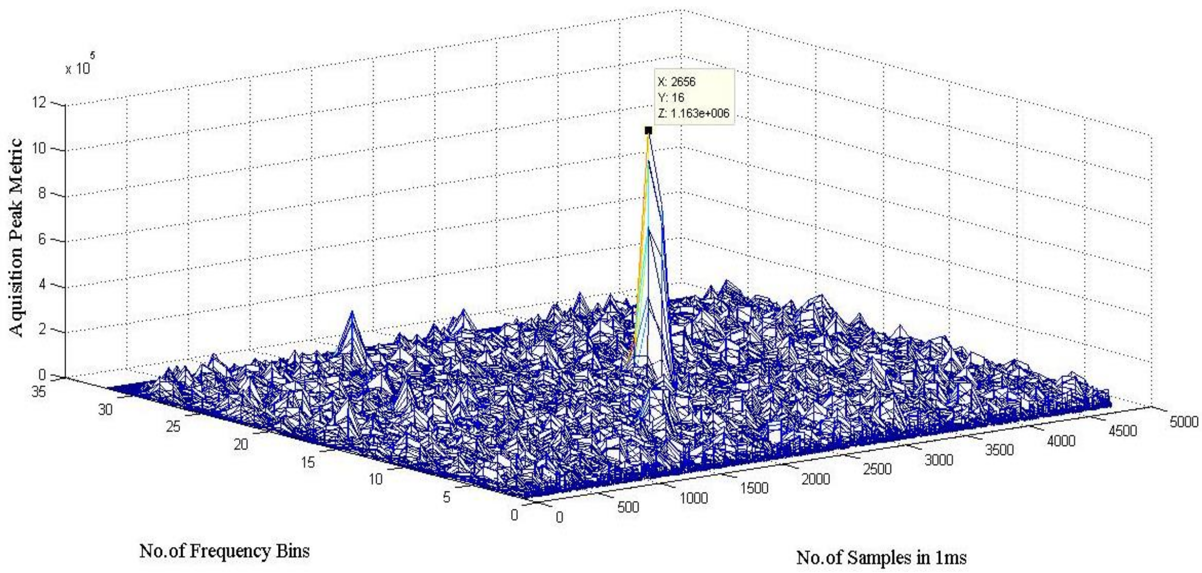

Figure 4.10: Acquisition of satellite 18 at IF with Doppler frequency bin number 16

In the process of searching visible satellites from the acquisition program returns the calculated position of the beginning of the C/A code and estimated carrier frequency. The Correlation Output of Input Signal and the C/A Code of Satellite 18 is shown in above figure. Similarly from Parallel code phase and Parallel frequency space search acquisition visible satellite of PRN 22 can be found and returns the codephase offset and estimated carrier frequency with Doppler shift, when it exceeds predetermined threshold. The visible satellite of PRN22 is shown in below figure.

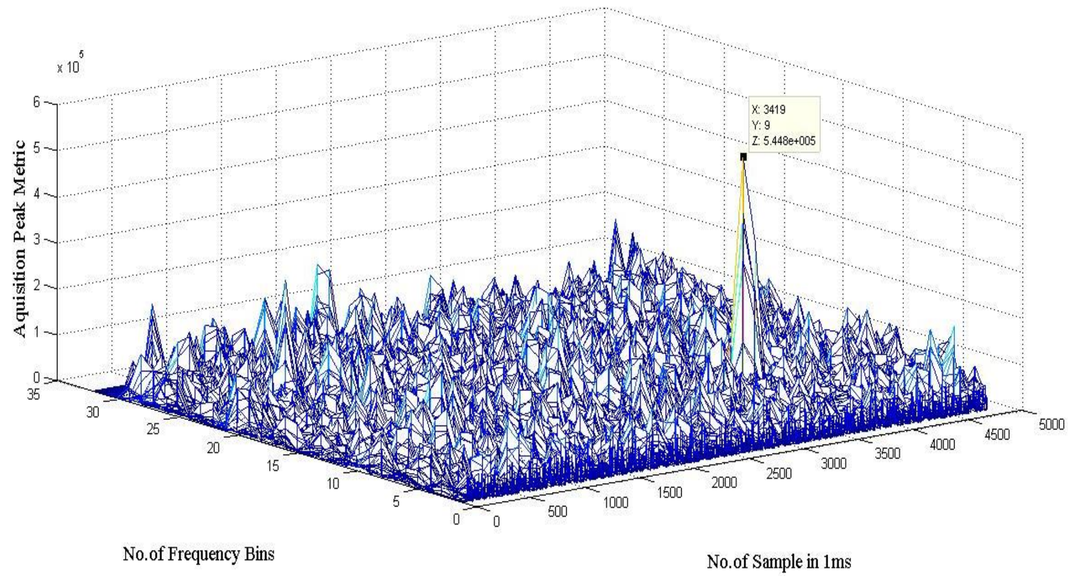

Figure 4.11: Acquisition of satellite 22 at IF with Doppler frequency bin number 9

Suppose after performing acquisition algorithm such as parallel frequency search method or serial search method, if no satellite is available in data signal means no satellite visible, because of it doesn't crosses predetermined threshold value hence satellite signal is not found. The below figure shows no satellites signal.

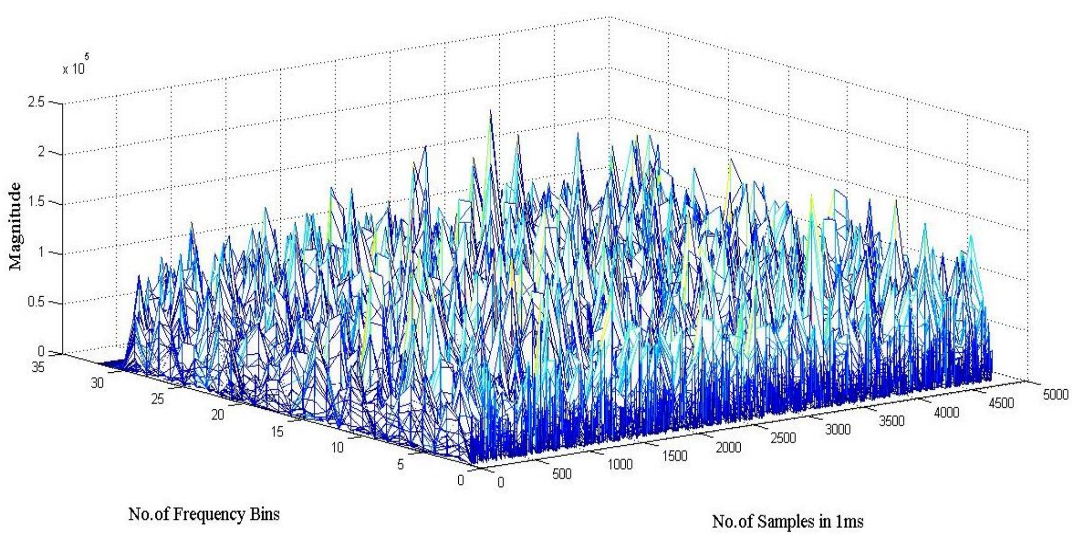

Figure 4.12: No satellite found for GPS satellite PRN 10

5. Conclusion and Future work

Global Navigation Satellite System has a wide research area and can be implemented in various real time applications. The project deals the development of baseband processing of GPS algorithms with FPGA. The goal of this work is to develop a GPS Software Receiver. To achieve this goal it was necessary to know base band processing of GPS software receiver. It includes acquisition; tracking and additional decoding algorithms have been used to compute receiver position for every millisecond. Here the acquisition is performed by using FFT search method and estimated codephase, carrier frequency values. After acquisition process completed, the estimated parameters are fed into the input of the tracking module.

FUTURE WORK

Development of baseband Processing algorithms for GPS L1-frequency C/A code and Implementation of baseband processing algorithms in Xilnix ISE has been completed and further need to do below tasks

- Verification of the implementation on FPGA with simulated data.
- Verification of the implementation on FPGA with the data collected from RF-front end.

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