Acquisition Strategies of GNSS Receiver

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***Abstract*— GNSS receiver performs many important operations out of which acquisition has the great importance. The performance of GNSS receiver is strongly influenced by the acquisition time. Acquisition provides rough estimate of code delay and Doppler frequency values of the received signal which plays very important role to synchronize local code with the received one. GNSS receiver effectiveness is usually the measure of the mean acquisition time. Simulation shows that time domain acquisition using serial search method requires very large acquisition time compared to parallel acquisition in time or frequency domain. Consequently, serial acquisition strategy is a straightforward process that provide better resolution and can be easily implemented on hardware GPS receivers.**

***Keywords*— GNSS Receiver, Correlation, Tracking, Acquisition,**

I. INTRODUCTION

Global Navigation Satellite Systems (GNSS) is a general term used for satellite navigation systems that provide global coverage. The satellite navigation system allows the receiver to determine their position from the line of sight signals received from different satellites in view. Different countries are developing their own GNSS system like Global Positioning System (GPS) of the United States and GLObal NAvigation Satellite System (GLONASS) of Russia. European union has introduced Galileo system which will be fully operational from 2013. China is planning to expand its regional Beidou system into Compass GNSS system by 2020. All GNSS systems have their own satellite constellation in the Medium Earth Orbit (MEO). The inter-operability of two or more GNSS systems in future will results in high positioning accuracy as more and more satellite will be in view.

The fundamental function of a GNSS receiver is to separate the signals in space (SIS) received from different satellites that are in view [1]. The GNSS receiver measures time of arrival (TOA) for each received signal and then demodulate navigation message to estimate the position, velocity and time (PVT) [2]. The basic approach of the GNSS receiver is based on the trilateration approach which measures the distance from three transmitters at known location as shown in Fig. 1. The receiver computes the TOA for each visible satellite and then estimates the pseudorange. Time synchronization of the receiver and satellites is very important requirement because the signal travels with the speed of light and synchronization error of 1 μs can generate error of about 300 m in distance. Thus, four pseudorange equations are required to calculate three user coordinates (x, y, z) and clock bias t_b due to synchronization. Since all the satellites are highly synchronized, therefore all TOA measurements at the receiver are effected by the same clock bias.

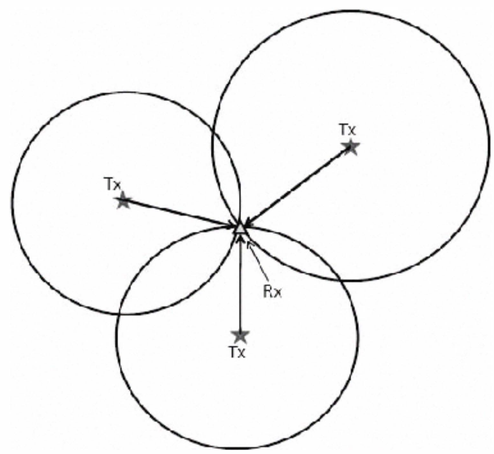

Fig. 1. Trilateration Approach

This paper presents some acquisition schemes used to detect visible satellites and find out coarse values for unknown code delay and Doppler frequency [3]. The hardware GPS receivers usually implement acquisition and tracking on ASIC chips because of its high speed to provide real time service. But the ASIC chip design is fixed and cannot be easily modified for other GPS signal processing algorithms. The software GPS receivers are very useful for test purpose compared to hardware GPS receivers. The software GPS receiver performs all signal processing on a high speed microprocessor and offer high flexibility.

The paper is organized as follows. Section II point out key challenges faced by GNSS receiver. Section III shows basic operations performed by a GNSS receiver. Section IV briefly describe correlation function used during acquisition. Section V represents acquisition strategies and their performances. Section VI presents MATLAB simulations. Finally, section VII concludes the paper.

II. GNSS RECEIVER CHALLENGES

The main goal of the GNSS receiver is not only to demodulate data but also to synchronize its local time scale with the GNSS time scale. Each satellite uses a different pseudorandom noise (PRN) code which allows

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the receiver to differentiate between the satellites using spread spectrum technique. The GNSS receiver faces a lot of key challenges. The received signal has very low signal to noise ratio (SNR) and usually suffers from the Doppler effect due to relative motion between the receiver and satellite. Differencing direct line of sight signal from multipath is also an important challenge for the receiver because sometimes no direct signal is available and the receiver considers one of the multipath component for position estimation [4]. The urban canyon causes the receiver to have fewer than four pseudorange measurements, thus makes the position estimation difficult. There are also many other interference sources from different radio technologies like UWB, WLAN, bluetooth etc which make the receiver task more complex [5]. Thus, the receiver has to find the unknown delay and Doppler frequency shift for each received signal during the acquisition phase.

III. Fundamental Operations of GNSS Receiver

A GNSS receiver is in charge of performing large number of operations. The receiver has an antenna with right hand circular polarization characteristics and hemispherical reception pattern. The signal from antenna is feeded into RF front end unit.

Since the received signal has very low SNR, thus it is first pre-amplified with low noise amplifier (LNA) to a proper amplitude and filtered [1]. The noise figure of LNA should be kept very low because the GPS signal is very weak and buried of noise. The signal is then down converted to suitable Intermediate Frequency (IF) and passed through analog to digital converter (ADC) to change the input signal into digital data at the earliest possible stage of receiver which is then decomposed on different channels in order to simultaneously elaborate different satellites data as shown in Fig. 2. Since each satellite has its own PN code, the signal is demodulated on each channel by generating PRN codes and applying spread spectrum technique [2]. Atleast four parallel channels are required to process signal from four satellites to find out the four unknowns (3 coordinates and time). Since more than 4 satellites are visible at some places therefore, the mass market GNSS receivers have usually 12 channels or more.

The GNSS receiver also extracts GPS signal code phase for pseudorange measurements and carrier phase for carrier phase measurements. The navigation block receives a constant data stream which consists of data stream from all visible satellites. For each satellite, it finds the ephemeris parameters which describe the actual satellite orbit and perturbation correction. The ephemeris data must pass the parity checking process before being utilized. The user location is estimated through least square (LS) algorithm, which is iterative process for estimating user location and clock bias. The least square algorithm is noisy and contain random errors equivalent to User Equivalent Range Error (UERE). In order to improve the quality of results and to have smoother user position estimation, Kalman filter or its extensions may be used.

The receiver demodulates the navigation message and computes the navigation solution, position, velocity and time (PVT). The major goal of the GNSS receiver is to reduce

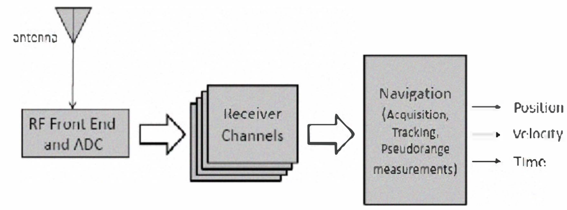

Fig. 2 GNSS Receiver Block Diagram.

Time To First Fix (TTFF) and estimate user position with high level of accuracy. The GNSS receiver synchronization process for the PN codes consists of two main steps, ‘Acquisition’ and ‘Tracking’ [6].

A. Acquisition Phase:

Acquisition phase determines the visible satellites and the coarse values of code delay and Dopper frequency for each received satellite signal [3]. The knowledge of delay is important in order to perfectly align the locally generated PRN code with the received one. Doppler frequency can have value up to ±5 kHz in case of stationary receiver. In general, all the operations that take place from the receiver start-up to signal detection and confirmation is called the acquisition phase [7]. Thus, acquisition is three-dimensional search phase which determines visible satellites ID (unique PRN code), code delay and Doppler frequency. Acquisition process takes help of the correlation function to identify signal parameters. The TTFF time strongly depends on the time required by the acquisition process. The TTFF time can be reduced by using information on the receiver previous position and almanac data. Thus, the GNSS receiver has two different start-up modes:

- Hot/Warm Start-Up: If the receiver is turned ON after a short time or it is continuously tracking its position like car GPS device then the TTFF time is very short because the information about the clock, almanac data and previous position is known to the receiver. This mode is called hot or warm start-up which uses reduced search space (codes and carrier frequencies) during the acquisition phase. Therefore, the search is optimized.
- Cold Start-Up: If the receiver is turned ON after a long time and/or at different geographical area then no external information is available to receiver. Thus, during the cold start-up, the receiver has to check for entire delay and Doppler possibilities (search space) which results in long acquisition process time.

B. Tracking Phase:

The tracking phase further refines the code delay and Doppler frequency estimates [8]. It keep the codes synchronized in order to dynamically recover delay between sequences and provide fine code alignment [3]. Thus, tracking phase uses the acquisition results and track the variation in code offset and Doppler frequency. The most commonly employed scheme for tracking is an Early-Late Delay Lock Loop (DLL) shown in Fig. 3. The local code and carrier replica are generated in advance and stored in the memory for its repetitive use during the signal acquisition and tracking. The DLL uses closed loop architecture and is based on the PN sequence autocorrelation. Since, the local generated code is stored in buffer, the buffer size should be equal to the length of the code.

The local code is fixed to the estimated delay value and correlated with the received one. The numerical control oscillator (NCO) makes possible to generate the estimated phase whose complex combined exponential is then applied to the entering signal. The output speed of NCO is controlled by the input. The discriminator consists of the DLL and PLL. DLL is used for code phase tracking and FLL and PLL are used for tracking carrier frequency and phase respectively. During the tracking process, the code generator produces PRN code of the same phase as the incoming data. To keep track of the acquired satellites, the carrier frequency and code phase is kept locked.

The tracking accuracy and performance is improved by using codeshift register which produces three different phases (Early, Prompt, Late) of PRN code. All these three code versions are fed in correlators and multiplied with the incoming data from which the carrier frequency has already been removed. The output of the correlators is provided to integration block where it is integrated over one code period. After correlation and accumulation, peak value of different phases are compared. The comparison of these three peak values will help to determine the bias if the incoming data undergo misalignment with the replica. The correction information is then sent back to the carrier NCO through Frequency Locked Loop and to Code NCO through Delay Locked Loop. Thus, new code phase and carrier frequency is adjusted to keep track of the incoming signal and thus, keep the visible satellites locked. The prompt code is required to match with the C/A code in input signal. The discriminator algorithm helps to accurately determine the beginning of C/A code in the input signal. This information is then used to adjust the initial phase of the local generated prompt code. Generally, the output of discriminator block can be expressed as:

$$\epsilon = \frac{y_E}{y_L}, \tag{1}$$

where y_E and y_L represents the correlation powers for the early and late versions of the code, respectively. The prompt code will be perfectly aligned with the C/A code of input signal if $\epsilon = 1$. If $\epsilon > 1.1$ then local code must be shifted to the right and if $\epsilon < 0.9$ then the local code must be shifted to the left.

IV. Correlation Functions

The correlation function (CF) is used to synchronize the local time scale with the GNSS time scale in order to make correct distance measurements.

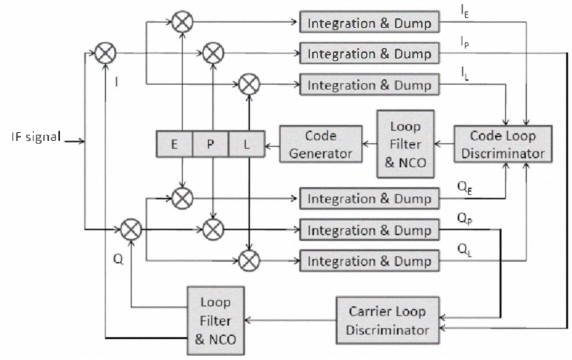

Fig. 3 Early-Late DLL Architecture.

Such synchronization is obtained by aligning the incoming PN code with the local replica. Thus, the CF is very important for acquisition and tracking phases [8]. The correlation helps to roughly estimate the delay and Doppler effect during the acquisition phase [6]. Circular correlation is a common term used in FFT based acquisition. Usually the received signal is periodic because the GNSS receiver continuously receive sequence of samples. Thus, the correlation takes place between a short locally generated code and long periodic incoming code which results in circular correlation. The circular correlation between two finite length signals *x(n)* and *y(n)* with length *N* can be expressed as:

$$z(n) = \sum_{m=0}^{N-1} x(m)y(n+m)\,, \tag{2}$$

Circular correlation is directly related to the properties of Fast Fourier Transform (FFT) which is extensively used in GNSS receiver particularly during acquisition phase.

V. Acquisition Strategies

The main objective of acquisition is to synchronize the incoming code with the local code in order to roughly estimate the delay and Doppler shift [3]. A general equation of the received signal from *i*-th satellite can be expressed as follows:

$$x_i(t) = AD(t-\tau^D)C(t-\tau)\cos(2\pi(f_{IF}+f_d)t+\varphi), \tag{3}$$

where A represents the signal amplitude. $C(t-\tau)$ represents the delayed version of the C/A code with a code phase delay of τ, $D(t-\tau^D)$ is the navigation data with a delay of τ^D, φ is the phase of received signal and f_{IF} represents the intermediate frequency. The first step of acquisition is the global search to estimate delay τ and Doppler shift f_d. There are usually 1023 code phases and ±IO KHz possible Doppler frequency bins to be searched. The cross ambiguity function (CAF) is evaluated on the received signal in order to detect the satellite and estimate its parameters. The general idea used in GNSS receiver is to compute correlation and compare it with the pre-defined threshold.

Thus, acquisition is performed over entire 2-dimensional search space where each bin has dimensions of delay and Doppler frequency as shown in Fig. 4. Search space contains all possible delay and Doppler frequency values. The bin size is a trade-off between integration time and the desired performance. Bin size also depends on the sampling frequency and hardware constraints. Increasing the number of cells correspond to increased complexity but results in better estimation performance. There are different acquisition strategies based on the CAF evaluation method which are explained below.

A. *Acquisition in Time Domain with serial method:*

During the serial search method, each cell of the search space is checked one by one to find the unknown delay and Doppler frequency values. One chip at a time of incoming data is multiplied with a chip from PRN code replica. For this purpose, a local test signal is generated which is correlated with the incoming signal. The delay and Doppler frequency values of the test signal is changed step by step within the search space range and CAF is evaluated to detect the presence of satellite [9]. If no signal is found then the acquisition is continued with different Doppler frequeny bin. After checking all possible bin and no successful result is obtained then the system will change the satellite for which it is searching.

General representation for the serial acquisition is shown in Fig. 5. The algorithms is simply based on the multiplication of local generated PRN codes and local carrier signal replicas. The code generator generates PRN code for a specific satellite as every satellite has a unique PRN code. The incoming signal has three part: navigation data, carrier frequency and PRN code. Thus, acquisition helps to identify the satellite, from which the signal is received through the PRN code modulation. The incoming signal is first of all multiplied with the local generated carrier at the first mixer in order to get rid of the carrier frequency and image frequency produced during the down conversion process.

The multiplication with local generated carrier produces in-phase (I) component, and multiplication with the 90 degree phase shifted version of local generated carrier produces quadrature signal (Q). Thus, the incoming IF signal is divided into I (Inphase) and Q (Quadrature) part which have phase separation of 90 degrees. The signal is then multiplied with the local generated PRN code sequence. The square is the taken of the real and imaginary values of product and then they are added together. The square root will represent the amplitude of that search space bin. This amplitude is then check for the specific threshold value. If the amplitude is higher than the threshold value, then that specific bin will represent the beginning of C/A code on the delay axis and the peak generated by specific frequency represents the carrier frequency of the input signal. These results are then provided to the tracking block of the GPS receiver. The computation performance of a correlator with length L in serial search can be expressed as:

$$R_M : L^2$$

$$R_A : L(L-1)$$

Where R_M and R_A represent the number of real multiplications and additions, respectively.

B. *Acquisition in Time Domain using Parallel FFT:*

Acquisition with serial search method is two dimensional process combining C/A code phase and frequency. Thus, it is very time consuming to search for correct values of Doppler frequency and code delay. The acquisition time can be reduced considerably if one parameter either delay or Doppler frequency is eliminated from search procedure. Thus, parallel acquisition based on FFT and Inverted FFT can significantly reduce the acquisition time. Parallel acquisition convert the signal from time domain into frequency domain and thus, eliminate one parameter which shorten the acquisition time considerably.

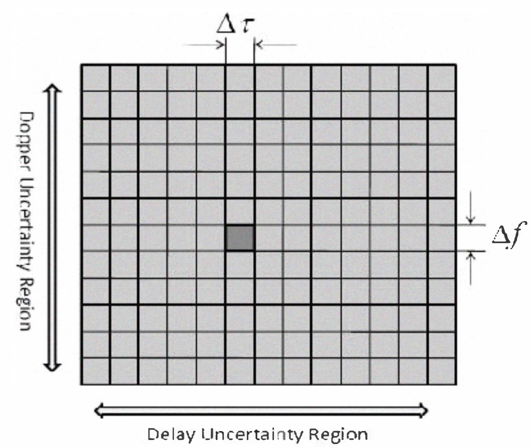

Fig. 4 Search Space.

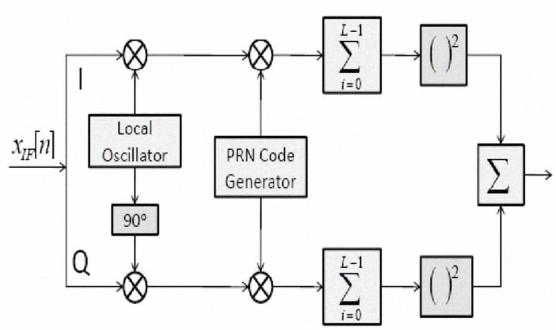

Fig. 5 Serial Search Acquisition.

Time domain parallel acquisition is also known as fast acquisition scheme which requires no more delay change. It checks all the delay values in one step for a particular Doppler frequency value over the search space [9]. The

Doppler frequency value of the local test signal is changed step by step which is then used to demodulate the received signal. The property of FFT is used to evaluate all the delay values in single shot [10].

General scheme for acquisition in time domain using parallel FFT is shown in Fig. 6. After the carrier removal from the input digitized IF signal, the in-phase and quadrature components are used as real and imaginary parts when computing the FFT. The result is then multiplied with the complex conjugate of FFT of the local generated code. The circular convolution is then obtained by taking the magnitude of the inverse FFT of resultant signal. Finally, the signal is passed through the threshold comparison for detecting the correlation peak.

C. *Acquisition in Frequency Domain using Parallel FFT:*

This acquisition scheme is also fast enough compared to acquisition with serial search method. This acquisition scheme does not require any change in Doppler frequency value for local test signal. It checks all the Doppler frequency values in one step for a particular delay value over the search space [11]. The delay of the local test signal is changed step by step which is then used to de-spread the received signal. The property of FFT is used to evaluate all the Doppler frequency values in single shot [10].

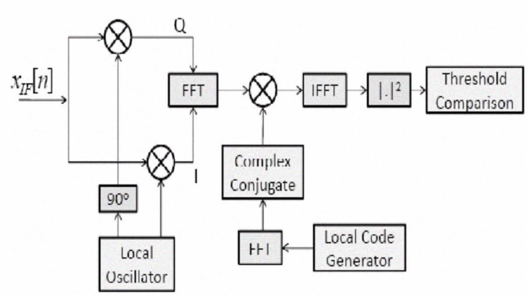

Fig. 6 Time domain Acquisition using Parallel FFT.

General scheme for acquisition in frequency domain using parallel FFT is shown in Fig. 7. When the C/A code is perfectly aligned, the Fourier transform output will generate a distinct peak in magnitude which will correspond to the carrier signal frequency. The accuracy of the frequency strongly depends on the number of analysed data samples and length of FFT and can be expressed as:

$$\Delta f = \frac{f_s/2}{N/2} = \frac{f_s}{N} \,, \tag{4}$$

where f_s represents sampling frequency and N is the number of samples. The accuracy of parallel frequency acquisition can be further improved with the increase in the length of FFT.

VI. MATLAB SIMULATIONS

The N-FUELS software is used to generate the code and signal sequences in order to check the performance of different acquisition strategies. N-FUELS provides a virtual environment to generate signals for GPS and Galileo systems with different characteristics e.g, modulation type, code number, front-end filter effects, quantization, disturbances and noise, delay and Doppler frequency etc. The graphical demo has been developed in MATLAB which is used to access the code and signals that are already generated by N-FUELS with different characteristics as shown in Fig. 8. Depending upon the settings, different algorithms are called by the GUI demo.

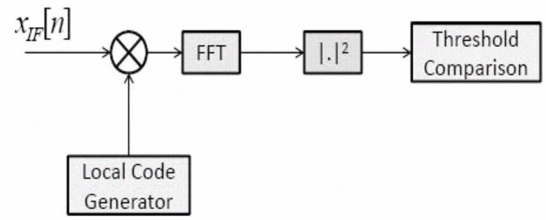

Fig. 7 Frequency domain Acquisition using Parallel FFT.

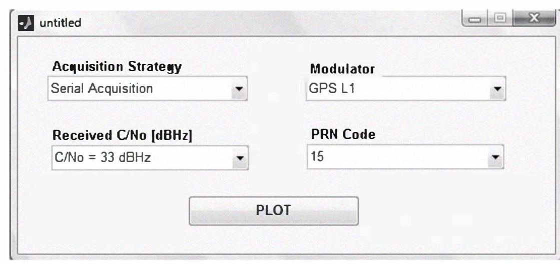

Fig. 8. GUI Demo.

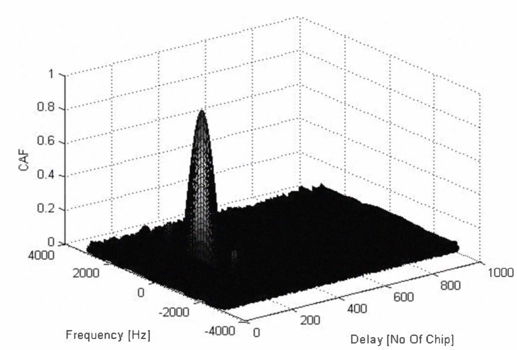

Fig. 9 3D Acquisition Plot

The GPS L1 band signal with Doppler shift of 1.5 kHz is processed for different acquisition strategies implemented in MATLAB. Fig. 9 shows the result of acquisition algorithms. Acquisition with serial search method requires large processing time compared to Parallel acquisition in time domain and frequency domain. It is obvious that all acquisition strategies provide same results but with different complexity and integration time. The parallel search in time domain and frequency domain is faster than the serial search because parallel search evaluates whole delay or Doppler frequencies possibilities in one step. The simulation has also been performed for different values of carrier to noise ratio C/N_o. Fig. 10 and Fig. 11 represents the CAF for C/N_o = 50dBHz and C/N_o = 30dBHz, respectively. It is obvious that the correlation peak detection becomes difficult for smaller values of C/N_o which makes difficult the satellite detection.

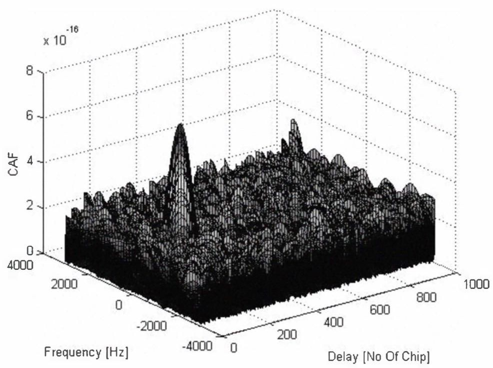

Fig. 10 Acquisition using C/No = 50 dBHz.

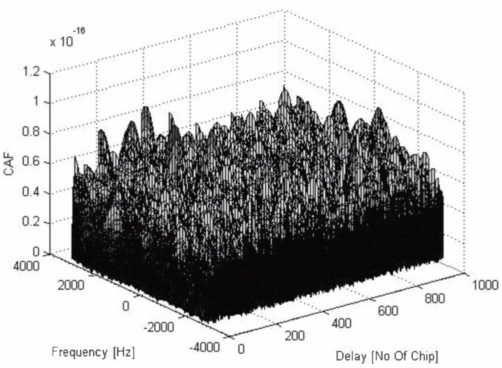

Fig. 11 Acquisition using C/No = 30 dBHz.

VII. CONCLUSIONS

This paper has presented different acquisition schemes of GNSS receivers. From the simulation, it was observed that acquisition time is very large for time domain acquisition with serial search method but its implementation is very straightforward and consists of simple multiplications and additions. On the other hand, time domain parallel acquisition employing FFT is a very fast acquisition strategy but the physical realization of FFT is very difficult and it consumes large hardware resources. Thus, FFT algorithms are very common for software GPS receiver but have very few applications in GPS hardware receivers. Serial search acquisition scheme is usually adopted in hardware GPS receivers because it is simple to implement. Thus, serial search is beneficial for commercial GNSS receivers and also lower the receiver cost significantly. But performing correlation over all the search space cells is very time consuming. Parallel acquisition based on FFT has better performance in terms of computation. The time domain parallel acquisition has larger number of search step compared to frequency domain parallel acquisition. Thus, GNSS receiver implements either of the acquisition strategy depending upon the requirement.

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