The Nucleus **51**, No. 1 (2014) 29-36

The Nucleus
A Quarterly Scientific Journal of Pakistan Atomic Energy Commission
NCLEAM, ISSN 0029-5698

SIMULATION AND ACQUISITION OF GPS L5 FREQUENCY SIGNAL AND COMPARISON WITH L1 SIGNAL

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(Received December 18, 2013 and accepted in revised form March 04, 2014)

Recent advances in GPS modernization efforts include transmission of L5 frequency signals. This paper emphasizes on the implementation of acquisition techniques for GPS L5 and GPS L1 signals. Both signals have been simulated and analysed in a detailed manner to obtain better acquisition results. In this context the signals have been generated, transmitted, received and acquired by suitable algorithms. Simulations were performed using Borland C++ Builder Compiler and MATLAB softwares. Results reveal that L5 signal offers many advantages, including that the acquisition peaks are more accurate, dominant and wider as compared to L1 signal, thus improving GPS system overall performance. Moreover, L5 signals reduce vulnerability to waveform deformation. Noise levels are also comparatively lower than previous signals.

Keywords: GPS, Acquisition, Correlation

1. Introduction

GPS stands for Global Positioning System. Initially, GPS system was developed for military purposes, however, it was made available for commercial applications and civil aviation in the early 1990's. Currently, GPS constellation consists of 32 satellites of which 24 are functional. These 24 satellites revolve around the earth's surface in six pre-determined orbits with each orbit having four satellites. Every orbit makes an angle of 60° along the earth's equator. The orbital radius is 26,560 km and time taken for one complete revolution is 11 hours 57 minutes and 57.26 seconds [1].

GPS satellites transmit modulated signal over different frequencies. Some other countries also have satellite navigation programs like GLONASS of Russia, COMPASS of China and Galileo of the European Union. These systems strive to provide (1) Superior satellite availability and frequency diversity (2) Improved signal power and (3) Signal formation innovations. Modernization of GPS signals include transmission of both civilian L5 signal and military signals L1C and L2C. Experimental L5 signal was transmitted from GPS IIR-20(M) satellite in 2009-2010. It is planned that GPS L5 signal will be available to all satellites in the year 2021 [2]. L5 signal comes third in civilian signal hierarchy, it provides better accuracy to navigation systems, provides higher bandwidth, the signal is operatable at higher altitudes and in severe multipath environments. Power levels of L5 signal are kept higher than previous signals, thus L5 signal can be easily picked up at elevated interference levels [2].

M.N.Venkatesh et al. have reported work on the structure of modern GPS L5 and L2C signals, their work explains the principle and generation approach of L5 signal and reflects the building process of modernized GPS system [3]. Similarly Stefan Erker et al. show the first measurement results and analysis of the new SVN49 L5 signal. Although this signal is only transmitted by a demonstration payload which fulfils International Transmission Unit (ITU) requirements to bring the L5 signal into use. The measurements of the first MEO L5 signal shows the enhanced L5 signal structure which will allow more accurate and reliable positioning when L5 signal is deployed [4].

This research work presents detailed information about GPS L1 and L5 signals structure and acquisition. Simulations have been performed and acquisition results are plotted and the two signals are compared in a detailed manner.

GPS satellites operate on two frequencies, 1575.42 MHz for L1 signal and 1227.6 MHz for L2 signal. The technique used for transmission of data from satellite to receiver is Code Division Multiple Access (CDMA) spread spectrum. A set of sequence called pseudo-random noise or PRN sequence is transmitted with the data, this sequence is helpful in recognition of the satellite. Each satellite has a different PRN sequence composed of random combination of +1 and -1. To acquire the original data, both receiver and transmitter must have knowledge about PRN sequence so that it can

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be exactly aligned, otherwise original data will be lost. GPS signal contains the Coarse Acquisition code and Precision code. These codes are separated by their availability and architecture. C/A is comparatively simple in architecture than Precision code that's why it is available to civilian users, while Precision Code is not available for civil applications due to its complex architecture and military objectives [5]. GPS system also contains information about the navigation and ephemeris data that is helpful in calculating position of the satellite and almanac data which contains information about satellite location and pseudo-random noise sequence.

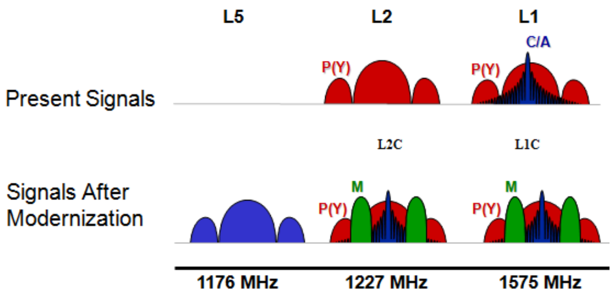


Figure 1. Post-Modernized Signals [6].

1.1. Modernized Signal Evolution

In Figure 1 present and post modernization signals are shown. This research work emphasizes on the GPS L5 signal. The signal was designed to provide enhanced cross-correlation side-peaks protection, improved narrow-band interference mitigation, instantaneous carrier phase ambiguity resolution for cm-level positioning, and improved multipath performance [2]. In this research work both GPS L5 and L1 signals have been selected for simulation and acquisition processes. Research work includes simulation of detailed GPS L1 and L5 signal generation and transmission scenarios using C++ builder. The output is a simulated string of GPS signals and later on these signals are acquired using MATLAB software. Furthermore, signal acquisition results have been analyzed for both L1 and L5 signals.

The results reveal that the simulation is successful and consistent. It is apprized that the acquisition of both L5 and L1 signal is performed for 1 milli second, but acquisition and correlation peak of L5 signal is much wider and dominant than L1. For similar acquisition time, noise level for L5 is also less than L1 signal. This proves that L5 signal is better as compared to L1 signal in terms of data integrity and acquisition sensitivity.

2. GPS L1 Signal

2.1. Signal Characteristics

GPS L1 signal can be modulated with pseudo random noise sequence using direct sequence spread spectrum (DSSS) method. We use this technique because it is resistant to interference and multiple users can be entertained on a single channel. L1 signal phase can be changed using binary phase shift keying. Bandwidth is set at 2.046 MHz. Data rate for navigation bits is kept at 50 bits per second [4]. GPS L1 standard equation can be written as: -

$$L1 = A1P(t)D(t)\cos(2\pi f1t + \Phi) + A2C(t)D(t)\sin(2\pi f1t + \Phi) \quad (1)$$

Where, A1 & A2 = Amplitude of the P code and C/A code respectively, P(t) = ±1 is the phase of the P code, D(t) represents navigation data, C(t) = ±1 is the phase of the C/A code, f1 is L1 frequency that is 1575.42 MHz and Φ represent phase of L1 signal [4].

2.2. Coarse Acquisition Code of GPS L1 Signal

In this paper C/A code is designed in both C++ and MATLAB environments. Length of this pseudo random noise sequence is set at 1023 bits. It is necessary that transmitted and received PRN sequences correlate such that desired satellite can be selected and data can be received. Every satellite has its own different PRN sequence that does not match up with any other satellite. This sequence can be generated using two feedback registers R1 and R2. These codes are also called gold codes. Registers are of 10 bit length and have ability to shift bits. Maximum length of PRN sequence can be achieved by given formula i.e. $L=2^{10}-1$. Both registers are initially set at 1. Clock Rate is kept at 1.023 MHz and it is repeated after one every milli second. The code is generated by taking Exclusive-OR of delayed output values of R2 register and R1 register direct values. The sequence that comes after Exclusive-OR is only transmitted at L1, sequence is not encoded or encrypted that's why it can be easily acquired by any GPS user. All the sequences generated by R1 and R2 have low cross correlation characteristics. Therefore, GPS space segment can select between best 37 Gold codes combinations that have low cross correlation characteristics [4].

2.3. Correlation Properties of C/A Code

Autocorrelation can be interpreted as multiplication of signal with its delayed replica. Auto correlation is performed with the pseudorandom noise sequence and is necessary part of acquisition process. Generally it can be denoted as

$$R(\tau) = \frac{1}{1023TCA} \int_{t=0}^{1023} Rj(T)Rj(T+\tau) \quad (2)$$

where, Rj (T) = C/A code sequence, j is satellite vehicle number and τ = time shift [8].

3. Thermal Noise

In this research, thermal noise factor has been added during simulation for both GPS L1 and L5 frequencies, to replicate real life conditions. Thermal noise effects transmission of signal from satellite to receiver. Thermal noise factor is similar for both GPS L1 and L5 signals. Standard equation for thermal noise is given as:

$$N = \sqrt{4kTRB} \quad (3)$$

where N is thermal noise, K is Boltzmann's constant, T is noise temperature and B is noise bandwidth.

4. GPS L5 Frequency

4.1. Signal Characteristics

GPS modernization includes addition of L5 signal that is transmitted at a center frequency of 1176.45 MHz, whereas the signal bandwidth is 24 MHz. The signal offers advancements in GPS signal structure. It is also known as life saving signal because of its precise navigation and positioning for aviation applications. In this research work detail simulation of L5 signal is performed and results are presented and observed. It is apprized that the L5 signal is better than existing L1 signal in numerous ways, some of them are discussed below, the L5 signal uses a chipping rate of 10.23 MHz which is 10 times the chipping rate of L1 signal. L5 spreading codes are also ten times larger than L1 signal [7]. L5 offers limited tracking errors and it is resistant to multipath interferences. L5 also improves inconsistencies of L1 signal coarse acquisition or C/A code. Presently, two satellites SVN49 and SVN62 are operating on L5 frequency on trial basis and it is expected that in future L5 will be broadcasted by all GPS Satellites [11]. GPS L5 standard equation can be written as:

$$L5(t) = \sqrt{2P(}(PNi(t)N(t)D(t)H10(t) \\ \cos(2\pi fLt + \Phi)) + \sqrt{2P(}PNq(t)H20(t) \\ \sin(2\pi fLt + \Phi)) \quad (4)$$

where L5(t) is the L5 signal, P defines power of signal, N(t) defines navigation data, Φ is phase, H10(t) and H20(t) is the Neumann-Hoffmann sequence, PN (i,q) define PN codes for in phase and quadrature phase components [8].

4.2. Coarse Acquisition of GPS L5 Signal

During this research endeavor a GPS L5 signal generator has also been prepared. The length of PRN sequence is set at 10230 bits with clock rate of 10.23 MHz that repeats itself after each milli second. The L5 signal also contains in-phase (I) and quadrature-phase (Q) components. Power levels for In-phase and Quadrature-phase components are kept same during simulations. The minimum received power for L5 signal is -157.9 dBW, which is 0.6 dB higher than the legacy L1 C/A code signal. Both components carry different but orthogonal and time synchronized PRN Codes. The Quadrature-phase channel is kept data less. The L5 signal only transmits a pilot signal modulated with the specific satellite PRN that is helpful for a long coherent integration time. Whereas, the in-phase channel and the navigation message are modulated with data rate of 100 symbols per seconds. L5 signal uses a Neumann-Hoffman (NH) synchronization code so that correlation properties can be improved. During simulation two different pseudo random noise sequences are used that helps to stop probable tracking biases, the in-phase and quadrature-phase component are XOR with XA, XB, XBi and XBq registers with clock rate of 10.23 M bits per second. XA and XB are 13 bit registers. Initially, XA and XB register length is set to 8190 and for initial condition, ones are stored in every single bit. The values of register XA will restart after every one milli second. This is done for total 10230 bits. Registers XBi and XBq length is set to 8191. These registers also run for one milli second duration and are restarted on completion. XBi and XBq are also synchronized with XA register. Code phase table of length 8057 is also defined for L5 signal during programming to achieve high correlation characteristics, so that it can be easily detected by the desired satellite for data acquisition. The XBi and XBq components can be differentiated by giving circular shift to values of XB register and utilizing code phase table of L5. The GPS L5 signal has been simulated and auto correlation plots have been shown and discussed later in the research paper.

4.3. Navigation Data Modulation

The designed navigation block of GPS L5 navigation data is similar to L1 navigation data. Research work does not include any position calculation process that’s why L5 data message is generated randomly using binary bits. Navigation data is modulated with signal with a data rate of one hundred sps. Navigation data is ½ convolved with main data bits. After that sequence is XOR with in- phase component of PRN sequence [9].

4.4. Neuman Hoffman Code

In this paper Neuman Hoffman Code is used because it cuts back cross correlation small peaks that arise with main acquisition peaks and it also helps in decreasing overall noise of the system. For signal modulation two Neuman Hoffman Codes are used having 10 and 20 bits. The 10 bit NH code has given data rate of one hundred symbols per second during encoding. Where '1' and '0' data symbol are represented by 1111001010 and 0000110101 respectively. The 10 bit NH code is further XOR with pseudorandom noise sequence at 1 kHz clock rate. Results have been modulated with 1176.45 MHz that is the L5 carrier Frequency. It is pertinent to mention that only in-phase component is modulated with carrier frequency and no quadrature-phase component is used because it is data less. But quadrature-phase component is encoded with 20 bit Neuman Hoffman Code which is further modulated with pseudorandom noise sequence at 1 kHz clock rate and thus results in 00000100110101001110 [10].

4.5. Signal Modulation

Figure 2 depicts the L5 signal modulation.

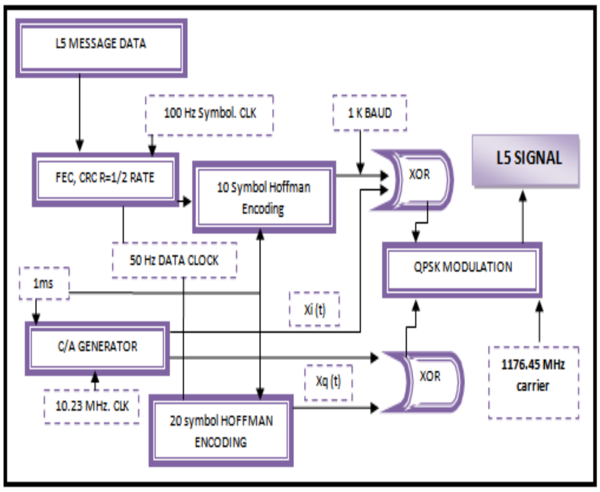


Figure 2. GPS L5 signal modulation diagram [10].

4.6. Properties of L1 and L5 Signals

Some of the properties and parameters of L1 and L5 signal applied during simulations have been compared in Table 1.

5. Signal Acquisition

Acquisition process is performed because it tells us about the presence of a satellite. Visibility of a satellite is essential for accurate reception of data and signal tracking. There are thirty two satellites orbiting around the earth and each satellite is assigned a unique pseudo random noise sequence. After successful acquisition, the receiver initiates loading the navigation and ephemeris data of desired satellite. Without acquisition process it is impossible to detect which satellite is broadcasting GPS signals. There are three widely used acquisition algorithms. The serial search method was one of simplest and first acquisition methods, whereas the parallel frequency space search method performs acquisition by taking Fourier transform. In this research endeavour, both L1 and L5 signals are acquired using parallel code phase search acquisition method [11].

Table 1. L1 and L5 signal properties

No.	Properties	GPS L1	GPS L5
1	Frequency [MHz]	1176.45	1575.42
2	Modulation Technique	BPSK	QPSK
3	Code Chipping Rate [Mcps]	1.023	10.23
4	Transmitted Power [dBW]	157	154
5	Code Length [Chips]	1023	10230
6	Navigation Data	Yes	Yes
7	Data Rate (symbols per second)	50	50
8	Secondary Code	No	Yes
9	Gold Code Register length	10	13

5.1. Parallel Code Phase Search Acquisition

We use Parallel code phase search method because it is the most computationally efficient acquisition method. Both L1 and L5 GPS signals are acquired using this method. In this method correlation is performed by taking fast Fourier transform. Signal received from satellite is multiplied by the carrier signal whose frequency is higher than the incoming signal, this frequency is generated locally. Thus we generate the in-phase and quadrature phase components of the signal. The quadrature-phase of the signal is generated by giving a phase shift of 90 degrees to the locally generated carrier signal. After that both in-phase and quadrature phase components are summed together to form a single signal. Fourier transform is applied to this signal. Equation can be written as:

$$A(k) = I(K) + Q(k) \tag{5}$$

Then a locally generated pseudorandom noise sequence is converted to frequency domain and result is complex conjugated. After this, signal A(K) is multiplied with the pseudorandom noise sequence. Inverse Fourier transform is applied to resultant signal that will convert signal to time domain. If we take absolute value of this time domain signal, the value will represent correlation between input signal and locally generated pseudo random noise Code. A higher correlation value will indicate that the satellite is available, which is our desired result. This whole process is shown in Figure 3 [11].

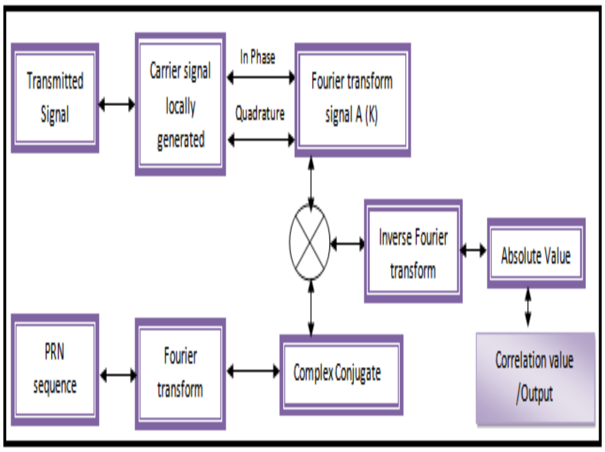


Figure 3. Parallel code phase search.

6. Simulations

In order to speed up the simulation process necessary coding has been performed using Borland C++ Builder compiler for GPS signal generation. MATLAB has been used at the receiver side to acquire the transmitted signal. The simulation process is divided in two phases, initial phase will generate the synthesized signal from GPS satellite and second phase will acquire the GPS signal and process it further. GPS L5 signal modulation and auto correlation graphs are plotted separately for more accurate results. Thus both L1 and L5 signals are generated according to their signal structures using C++ and later on acquired by the relevant MATLAB designed receivers.

6.1. Detailed MATLAB Code Description

As mentioned earlier both transmitter and receiver are simulated separately. The GPS signal after simulation is acquired in the receiver and if a signal is not present, correlation cannot be achieved and raw GPS data will not be acquired or displayed. The necessary parameters for the relevant PRN sequence, C/A code, ephemeris data and everything else are kept same for both receiver and transmitter. In order to understand the code a detailed flow chart is shown in Figure 4.

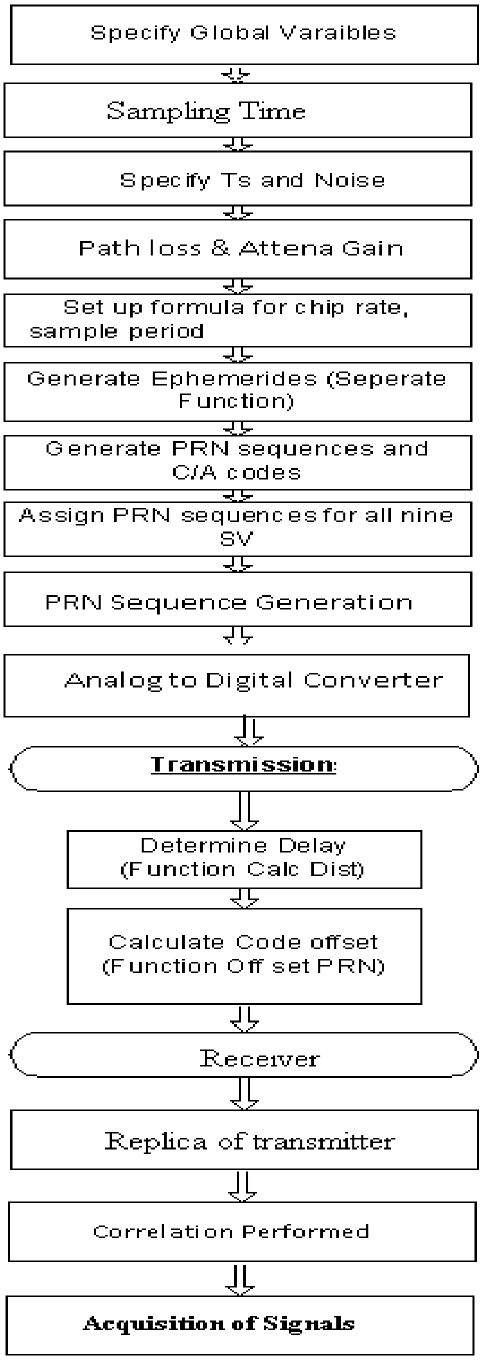


Figure 4. Acquisitions of GPS L1 & L5 signals.

7. Results and Analysis

7.1. L5 Signal Modulation Plots

The GPS L5 signal has been simulated and Figure 5 shows the modulated L5 signal. Both I and Q phases for 100 bits are also shown in first two plots of Figure 5.

It is apprized that Figure 6 shows in-phase and quadrature-phase components of L5 signal for 250 bits. For clearer results in-phase and quadrature phase components for 100 bits are also shown in next two sub plots depicting the relevant bit sequence.

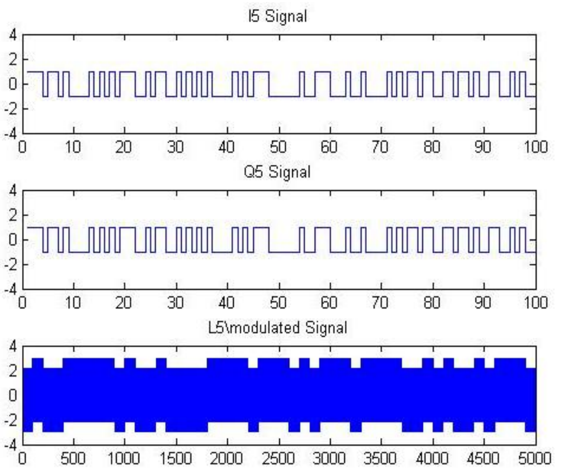


Figure 5. GPS In-phase, Quadrature-phase and signal modulation Plot for L5 Signal.

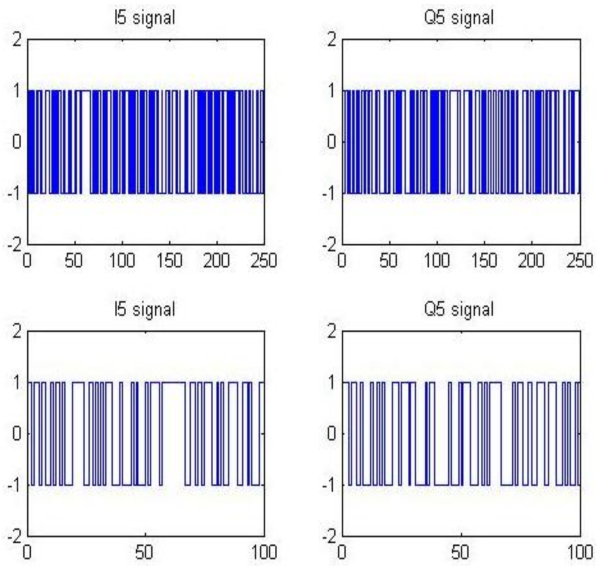


Figure 6. In-phase and Quadrature Phase Components for GPS L5 code.

7.2. *Auto Correlation Plot for L5 Signal*

The L5 signal has larger theoretical processing gain therefore it is easier to detect the L5 signal. The general auto correlation equation can be written as

$$A_{i,q}(\tau) = \int_{+\infty}^{-\infty} S(t)_{i,q} S_{i,q}(t-\tau)\, d\tau \qquad (6)$$

Where A(τ) show auto correlation, t is time.

Figure 7 shows the auto correlation plot for GPS L5 signal. It is apprized that the theoretical processing gain for L1 signal is 30 dB and for L5 signal it is 40 dB.

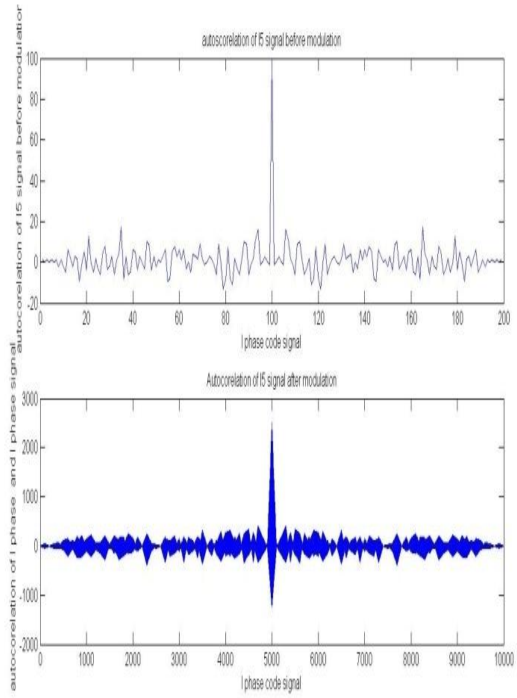


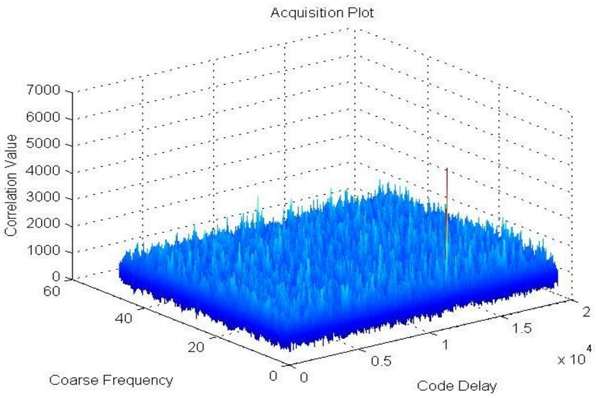
Figure 7. Auto Correlation Plots for GPS L5 Signal.

7.3. *Acquisitions Plots for GPS L1*

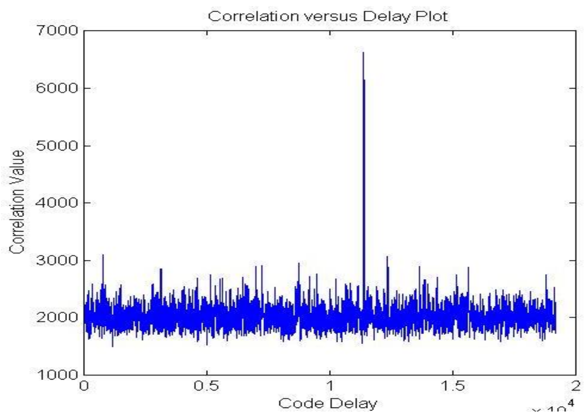
The acquisition plots are shown in Figure 8a and 8b for GPS L1 signal and Figure 9a and 9b depicts the acquisition plots for GPS L5 signal for similar acquisition time. Results have been obtained using the Parallel Code Phase Search Acquisition technique. Comparing plots for both L1 and L5 signals we can deduce that the acquisition peak for GPS L5 signal is much more dominant as compared to L1 signal. Therefore, L5 signal provides the required accuracy in the presence of noise and multipath. Results also reveal that L5 signal provides better signal integrity, can overcome false acquisition problems and also decrease susceptibility to interference.

Correlation peaks are shown in two dimensional format in case of figures 8b and 9b. It can be observed that noise floor of L5 signal is lower for same acquisition time and therefore acquisition peaks are more prominent. In Figure 8a, GPS L1 correlation value is about 7000 while L5 correlation value is about 10,0000 as shown in figure 9a). This huge difference in correlation value exhibits that L5 signal provides better signal and data integrity. Another plot for GPS L5 signal acquisition has been given in Figure 10, showing acquisition graph for PRN 10. The acquisition plots also reveal that L5 signal provides higher bandwidth efficiency, decrease susceptibility to wave form distortion and offers better accuracy than L1 signal. It is worth mentioning that acquisition time for both L1 and

L5 is kept same at one milli second, therefore we can safely conclude that L5 signal has superior detection properties. The below mention table defines the main simulation parameters and their corresponding values.

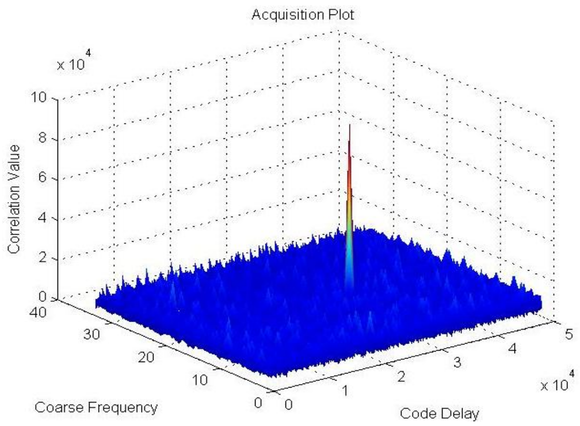


8a

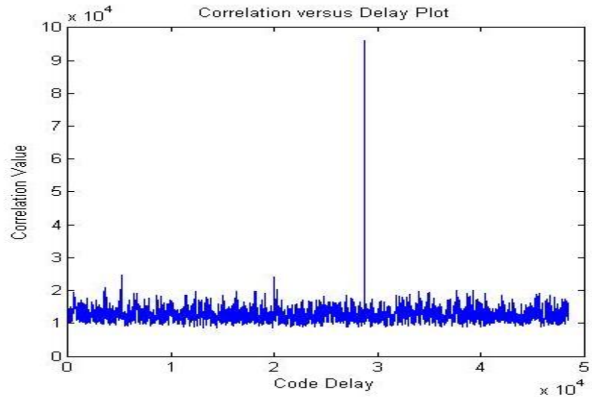


8b

Figure 8 a) Acquisition plot for GPS L1signal, b) Correlation vs. Code Delay plot for L1 signal.



(a)



9b

Figure 9. a) Acquisition plot for GPS L5 signal, PRN =7, b) Correlation vs. Code Delay plot.

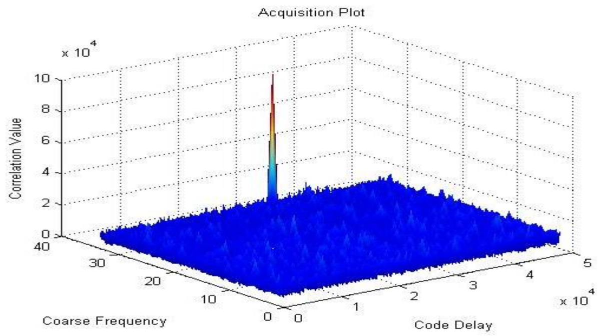


Figure 10. Acquisition plot for GPS L5, PRN =10.

Table 2. Simulation parameters

No.	Factors	GPS L1 Signal	GPS L5 Signal
1	Sampling Freq (MHz)	19.2	48
2	IF Frequency (MHz)	3.78	20
3	Carrier Frequency (MHz)	1575.42	1176.45
4	Duration(ms) for acquisition	1	1
5	Approximate Correlation Peaks maxima	7000	10,0000
6	Chip Rate(MHz)	1023	10230

8. Conclusions and Recommendations

In this research endeavour detailed simulation and acquisition of GPS L5 frequency signal and its comparison with L1 signal has been performed. The results reveal that trial based L5 signal has many advantages over already deployed L1 signals, including that the acquisition peak of L5 signal is much more dominant and signal has greater bandwidth than L1 signal. Thus enabling the L5 signal to be easily detectable by GPS receivers. Since correlation peaks of L5 signal are much larger than L1 signal, as shown in figures, it can be deduced that L5 signals have improved signal reliability and are more resistant to false acquisition problems. The Neumann Hoffman coding method is utilized in this work that helps in improving correlation values. Future research will concentrate on implementing the tracking and position calculation algorithms for GPS L5 frequency. The results also conclude that L5 signals will have more civilian applications due to improved signal acquisition. Post modernized signals are confirmed but not yet deployed on all satellites. But the GPS L5 signals have the potential to be applied in a lot of applications that will add precision and reliability to the current navigation systems.

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