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Indian Institute of Technology Jodhpur

DESIGN AND IMPLEMENTATION OF INTEGRATED GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS) RECEIVER

B.Tech Thesis Report

Submitted by

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Chapter I

INTRODUCTION AND PROBLEM DEFINITION

Satellite navigation systems help a user to determine position and accurate local time. Satellite systems that have global coverage are referred to as Global Navigation Satellite Systems. At present, there are two satellite navigation systems in operation – Global Positioning System (GPS), owned by the United States and Global Navigation Satellite System (GLONASS), owned by Russia. Several other systems are in the process of being established – Galileo (Europe), COMPASS (China) and Indian Regional Navigation Satellite System (IRNSS) (India).

Currently available receivers use 4 satellites of a single system to calculate the position solution by triangulation. However in urban areas with high rise buildings, satellites have to be at high enough elevation angles to be visible (see Figure 1). The probability that four satellites of a single system will be at this elevation is low, thus limiting the chances of obtaining a position fix. This problem assumes importance considering the fact that most of the users would be present in these urban areas.



Figure 1. Satellites have to be present at high elevation angles to be visible to the receiver in urban areas

This problem has been solved in Japan, by having an additional satellite system, called the Quasi Zenith Satellite System (QZSS), which is so designed such that satellites from this system will be present always at a high elevation angle, and augment the positioning provided by GPS (See Figure 2a). However, QZSS is a three satellite system, intended for service within the area of Japan. The number of satellites required and hence the cost would be more for providing similar services over larger countries such as India.

Another solution is to use a hybrid receiver, which has dedicated channels (4 each) for GPS and GLONASS (See Figure 2b). The drawback is that such a receiver can work only if 4 satellites, all from one system (either GPS or GLONASS) are present, for which the probability is again low. Moreover, it would be expensive to have 8 channels, besides making the receiver bulky and increasing power consumption, which would make it unsuitable for small consumer applications, such as in mobile handsets.

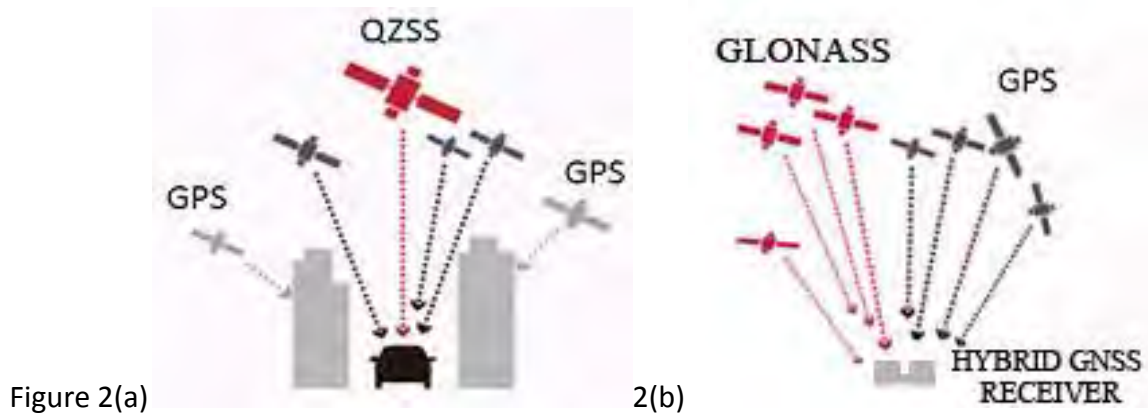


Figure 2 (a) QZSS system (b) Hybrid receiver

The solution that we propose, which also overcomes these challenges, is to use an integrated receiver, which uses the same 4 channels to obtain signals from 4 satellites, which may be any combination consisting of GPS and GLONASS satellites (2 GPS + 2 GLONASS or 1 GPS + 3 GLONASS etc.). Thus a position fix can be obtained if any 4 satellites from the total constellation of GPS and GLONASS (56 satellites) are at the required elevation, for which the probability is much higher compared to that for 4 satellites, all of which are from either constellation (28 satellites) (See Figure 3).



Figure 3. IGNSS receiver can compute the position solution, where a conventional receiver (GPS or GLONASS) or hybrid receiver cannot

An integrated receiver will have the following advantages:

- Improved Availability
- Improved Continuity

Continuity is the probability that the minimum number of satellites will continue to remain visible for the duration in which location information is needed. It is evident that a GNSS receiver will have improved continuity due to reasons stated previously.

- Improved Accuracy

Accuracy refers to the accuracy of location information. Since a GNSS receiver can utilise signals from any system, it can choose the optimal combination of five satellites to achieve maximum accuracy, as it will have more satellites to choose from at a given time.

- Integrity Information

Integrity is the ability of the system to inform the user if the calculated position information is unreliable as it may contain large errors. This capability is not supplied by any system (GPS or GLONASS). But a GNSS receiver can provide this information as it can compute position using different combinations of satellites and it can identify if one satellite is out of order as then those combinations involving that satellite will give location information with large error. A conventional receiver cannot give this information as it does not have the freedom to choose different combinations.

The final outcome of this project is to develop an integrated software defined radio (SDR) receiver for GNSS signals and develop a hardware prototype of the receiver if time permits.

Some major challenges that have to be overcome in this project are

- Integrating different coordinate systems used by each satellite system
- Designing correlation receivers for different message formats and modulation schemes through same channel and hardware
- Developing navigation software algorithm for Receiver Autonomous Integrity Monitoring (RAIM)
- Additional processing for Geometric Dilution of Precision (GDOP) calculation and integrity monitoring
- Algorithm for ionospheric correction to be included in navigation software
- Reducing algorithm complexity, and optimizing use of hardware resources so as to complete all additional operations in real time

Chapter II

PROGRESS OF THE PROJECT

The block diagram of a GNSS receiver is given in Figure 4.

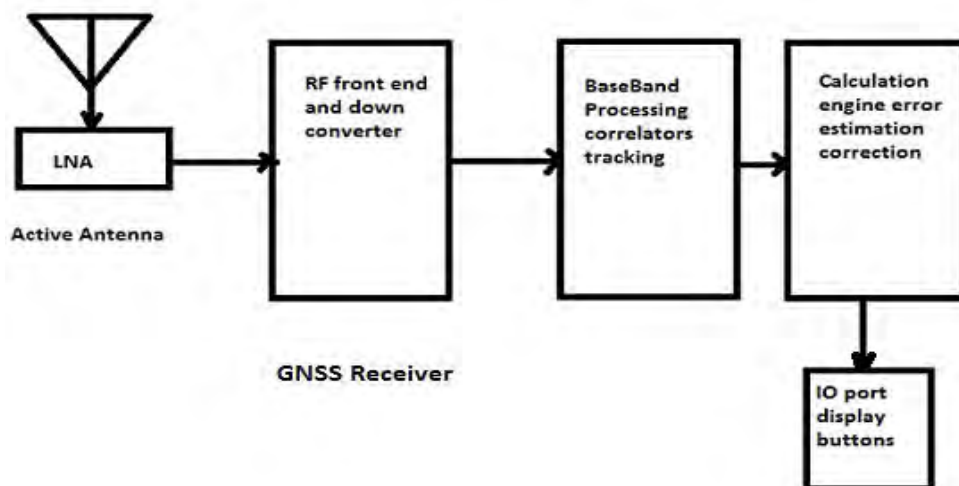


Figure 4. Block diagram of a GNSS receiver

In this semester, we worked on the most crucial component of GNSS receiver, namely the Correlator receiver, which correlates the incoming signal with delayed replicas of the Pseudo Random Noise (PRN) code, in order to determine the delay caused to the signal while travelling through the channel. The delay is used to determine the pseudo range values to the satellites, and obtain the position solution.

A simulation of the correlation receiver was developed in MATLAB. A random data sequence of length 10 bits was multiplied with the gold code for a GPS satellite. The bit sequence was modulated by Binary Phase Shift Keying (BPSK) modulation, which is used by GPS satellites in L1 C/A, L2C and L5 frequencies. The signal was delayed and noise was added according to a desired Carrier to Noise Ratio (CNR) value. The signal was filtered by a low pass filter of appropriate cut off frequency to the received signal at the correlator input.

In the absence of noise, the signal can be tracked by the correlator receiver by using a single correlator. The signal would be tracked when the correlation value exceeds a preset threshold. However, if noise is present, it may cause the correlation values near the actual correlation

peak to exceed the peak value or the threshold, thus causing error in delay determination (see Figure 5). To solve this problem, instead of a simple threshold detection, a scheme involving parallel correlators was implemented, which is described as follows.

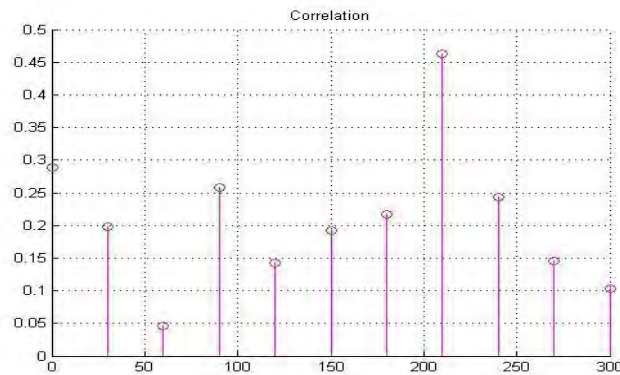


Figure 5. Correlation function in the presence of noise (CNR = 10dB) Actual delay value = 314

At the correlator receiver, three delayed replicas of the PRN code were generated, successively delayed by half a chip. These were used to run three parallel correlators (Early, Late and Prompt) for correlating the code with the input signal.

The correlator receiver has two loops –acquisition and tracking. In the acquisition loop, the three correlators were advanced by thrice of half-chip duration, and the loop is broken when any of the three correlators exceeds the threshold value, giving an approximate value of the delay. Then the receiver enters into the tracking loop, where the three correlators are advanced by a single sample. When early correlation becomes equal to the late correlation the signal is tracked, and delay determined, which is used to estimate the pseudo range. The delay value determined can then be also used to decode the received signal and obtain the input bits of the navigation message.

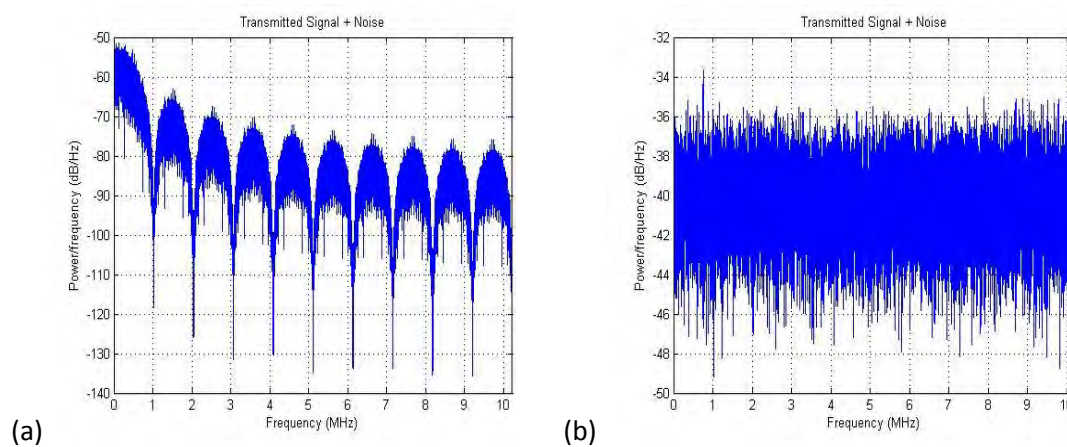


Figure 6. BPSK Transmitted Signal + Noise Spectrum (a)CNR = 300dB (b)CNR = 10dB

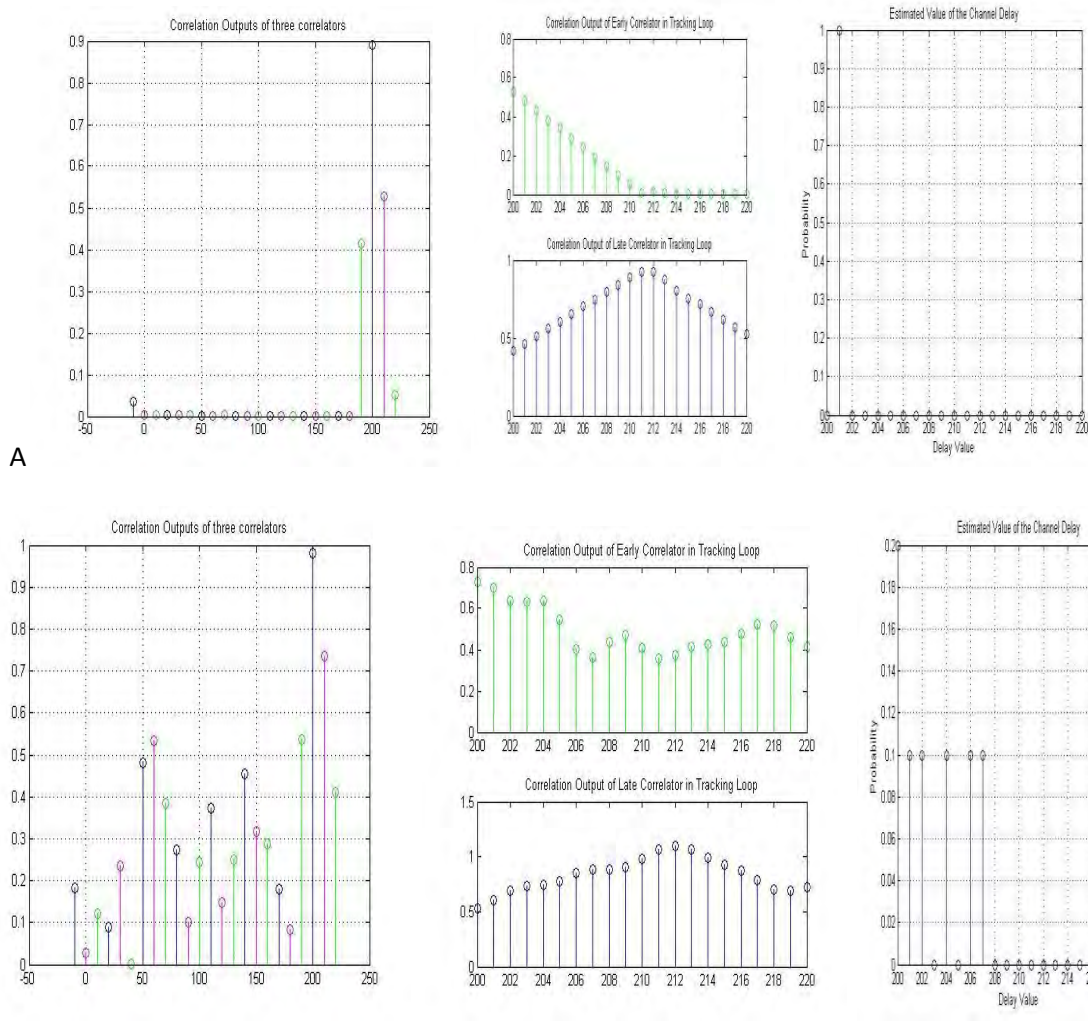


Figure 7. Correlation Outputs for A. CNR = 300dB B. CNR = 10dB

The modernized L1C frequency of GPS and other satellite navigation systems which are being established uses Binary Offset Carrier (BOC) modulation, where a square wave subcarrier is multiplied with the signal. The autocorrelation function for BOC modulated signals are as given in figure 8a. As can be seen from the plot, the delay cannot be accurately determined even using three correlations functions as there are multiple peaks or ‘triangles’ around the actual correlation peak. Early correlation will be equal to Late correlation with Prompt having a high value at each of these peaks, thus giving an incorrect estimate of the peak. Hence we need to use two additional correlators – Very Early and Very Late. The signal would be tracked only when Early = Late and Very Early = Very Late.

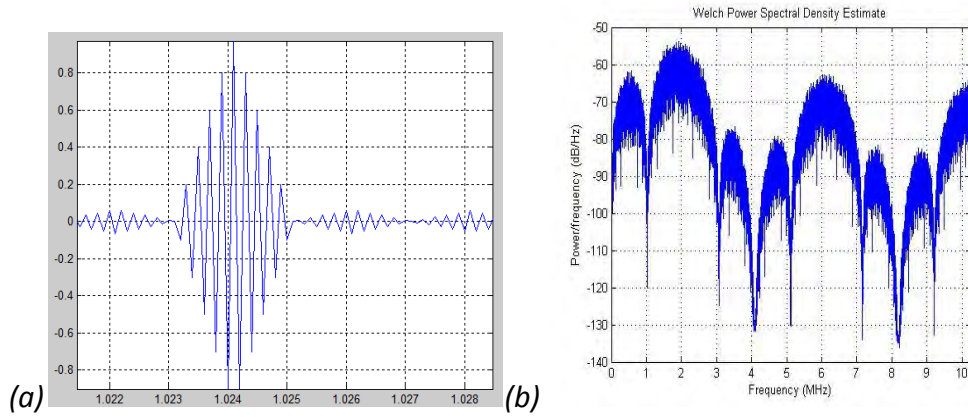


Figure 8.(a) Autocorrelation function of BOC modulated signal (b) BOC spectrum

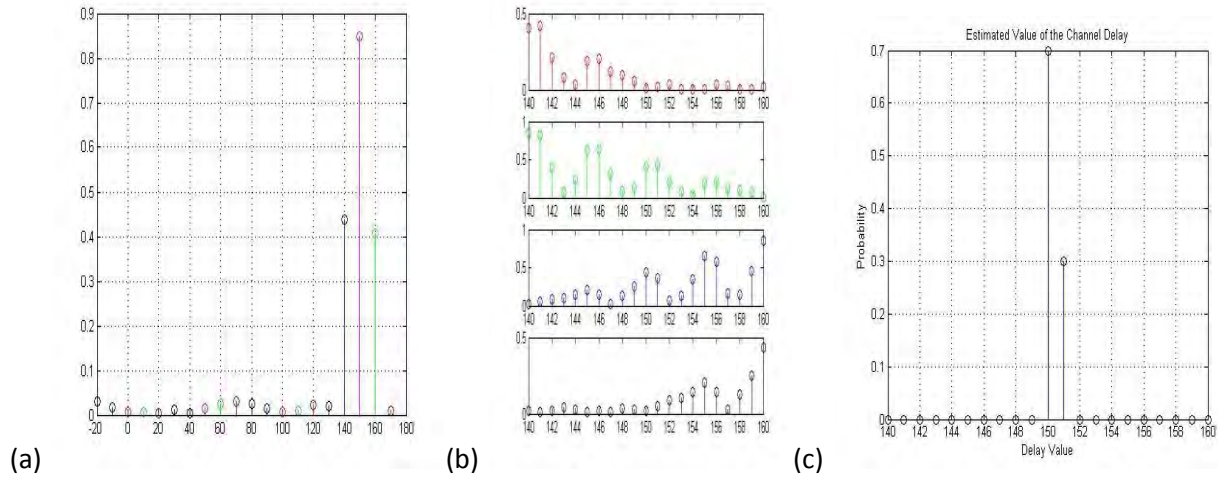


Figure 9 CNR = 30dB, Delay = 150 chips (a)Five Correlator Outputs (Acquisition loop)

(b)VE, E, L, VL Correlators (Tracking loop) (c) Delay Estimate

Different discriminators were examined in order to determine the best performing one to be used in the tracking loop. The delay estimate shown in figure 9c, is given by a discriminator of the form $(E - L) + (VE - VL) + (1 - P)$, which gave the best accuracy of all. The delay estimates by different discriminators, for an actual delay of 150 chips are as given in Figure 10 (all estimates at CNR = 30dB). It was seen that $(Early - Late) + (1 - Prompt)$ had the best accuracy. Early-Late Power and $(Early-Late)/Prompt$ will also be considered for implementation after examining the dynamic range of each with respect to CNR, and hardware resources available.

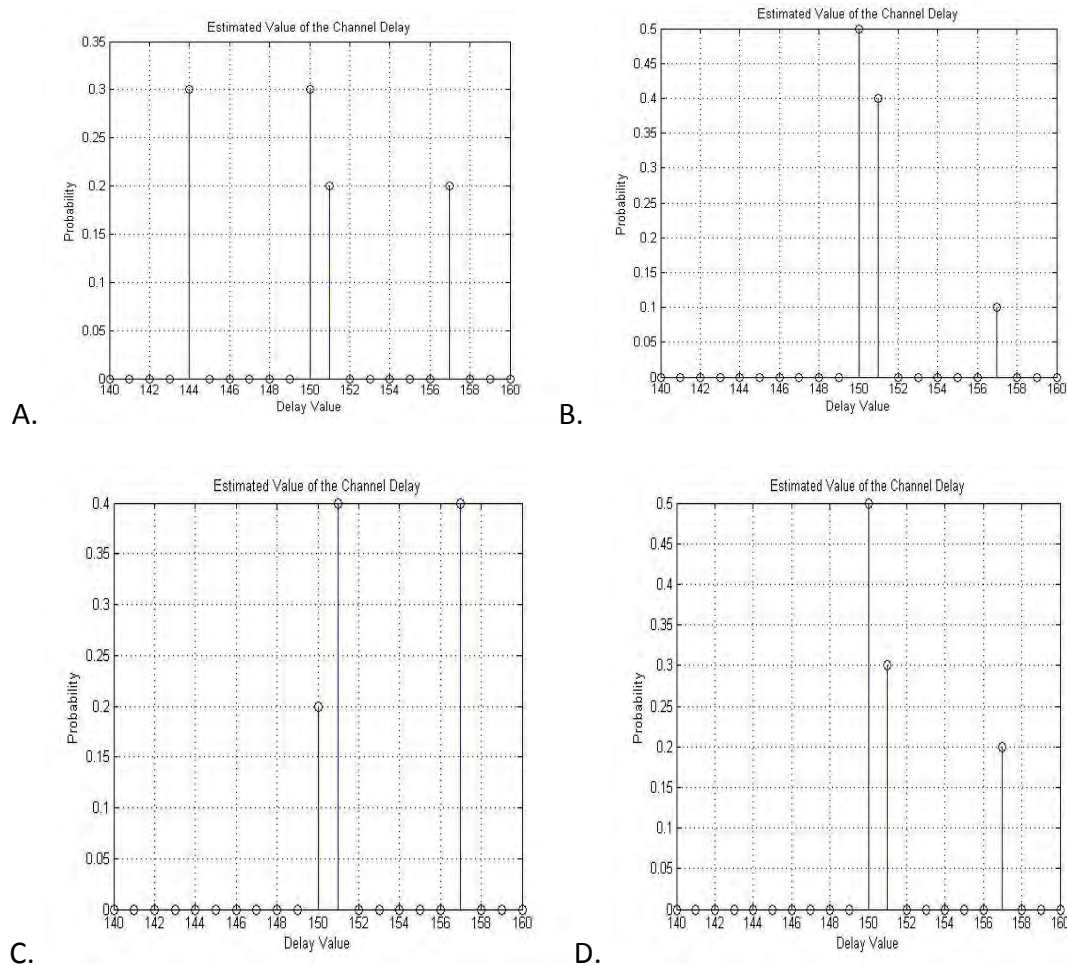


Figure 10. Delay estimates of different discriminators; CNR=30dB Delay = 150 chips (a) Normalized Early – Late Envelope (b) Early – Late Envelope (c) Early-Late Power (d) (Early-Late)/Prompt

GNSS Signal Simulator

Our focus is on the generation of GNSS signal for testing the correlational receiver. GNSS consists of GPS and Glonass Signals. Random 10- bit data was chosen in place of navigation data as we perform the testing. We have data Spectrum as shown in the figure:

Data = [1 1 0 0 0 0 0 0 0 0 0 0 0];

Sampling Frequency= 1.023e6;

GPS Specifications	GLONASS Specifications
Data rate= 500 bps	Data Rate = 50 bps
Chip Rate= 1.023e6	Chip Rate = 500kbps

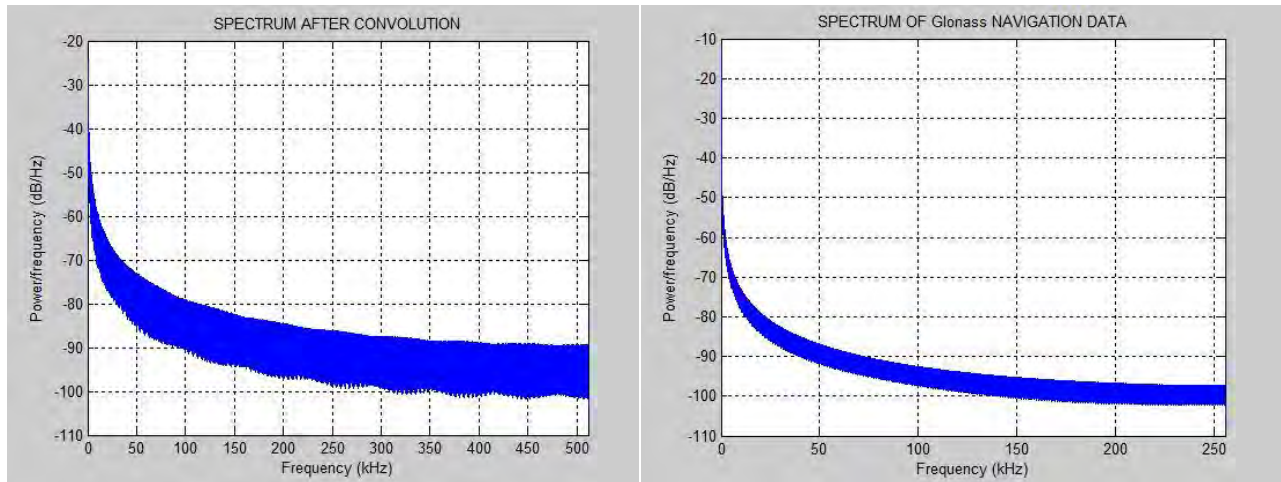


Figure 11: Data Spectrum of GPS(left) and Glonass(right)

We used the PRN codes of three distinct satellites such as satellite PRN Number 127, 128 [Ref: Understanding GPS]. We generated different PRN codes using different gold codes. In a similar way, codes are created for Glonass satellite system. The following is the spectrum of code spectrum of GPS L5 signal with data spreaded over the entire spectrum.

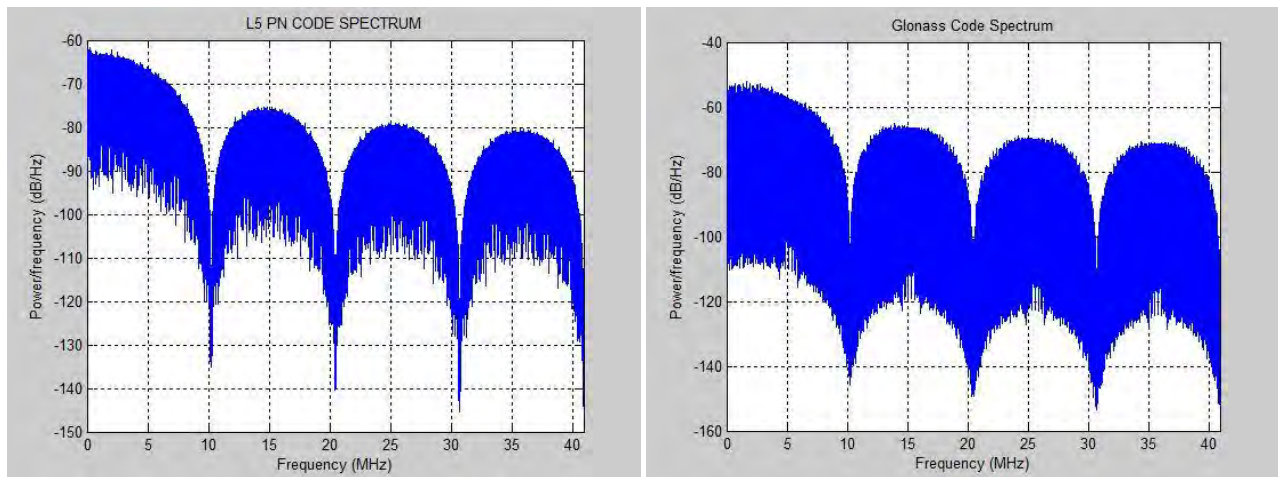


Figure 12 : GPS L5 code Spectrum(Left) and Glonass Code Spectrum(Right)

We created similar data-code spectrum for the three satellites. Subsequently, we added all the three satellite signals and gave it as input to the correlational receiver and decoded the bits. The correlational receiver identifies the appropriate satellite and it acquires the satellite signal and tracks it. We provided the following mixed signal code spectrum to the receiver and we noted that receiver decoded the data.

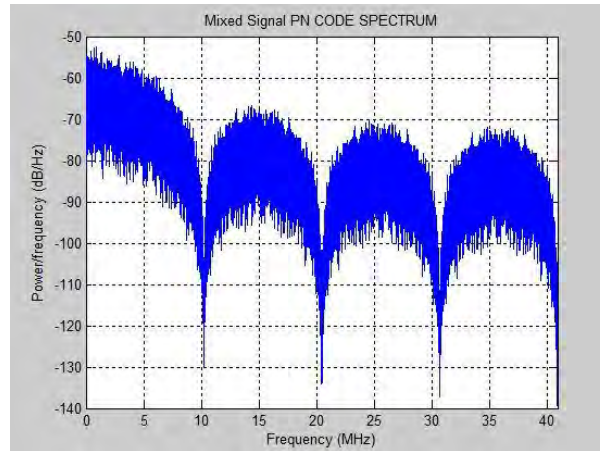


Figure 13: Mixed signal code Spectrum

FUTURE WORK

TASK	TIME OF COMPLETION
Develop Integrated GNSS Software Defined Radio (SDR) Receiver	Early February, 2014
Testing of SDR with simulated signals	Late February, 2014
Develop Hardware GNSS Receiver Prototype	Late March, 2014
Final Testing with real GNSS signals	April, 2014

REFERENCES

GPS/GLONASS Interface Control Documents

1. IS-GPS-200G
2. IS-GPS-705C
3. IS-GPS-800C
4. ICD-GLONASS-5.1-(2008)

Books

5. *Understanding GPS: Principles and Applications* by E.D Kaplan and C.J Hegarty