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IMPLEMENTATION OF CONVENTIONAL SOFTWARE GPS RECEIVER TO ACQUIRE AND TRACK GPS SIGNAL

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ABSTRACT

The GPS signals when transmitted from the satellite have power of 27 W. As they reach the receiver antenna on the earth's surface, the power measured is too low around 10^{-16} W. So, the acquisition and tracking of GPS signals become a big challenge. Acquisition and tracking of GPS signal are the initial stages in the software GPS receiver. Acquisition stage detects the signal coming from the satellite and provides rough estimate of code phase (code delay) and doppler frequency. Tracking phase provides the sheer estimate of the code phase and doppler frequency, which helps us to determine the distance between the receiver and the satellite transmitting the signal. In hardware GPS receivers a specialized chip is being designed for performing acquisition and tracking algorithms. While in software GPS receivers, the signal processing tasks are performed in software. Thereby, increasing the control and flexibility on the tasks performed. It also becomes easy to incorporate any changes in algorithms or approaches in the future. In this paper, we have demonstrated the acquisition and tracking of GPS signals data affected by ionospheric scintillation using software GPS receiver. The acquisition of GPS signals is implemented using a Parallel code phase algorithm and its tracking using DLL/PLL.

Keywords: acquisition, tracking, code delay, doppler frequency, software GPS receiver, ionospheric scintillation, parallel code phase, DLL, PLL.

INTRODUCTION

U.S. has developed, GPS (Global Positioning System), which is basically radio navigation system. GPS has diverse applications in military navigation, aircraft navigation, land mobile navigation, marine navigation, spacecraft orbit determination, ionospheric measurement, surveying and many other. It represents the realization of different technologies like atomic frequency standards, spread spectrum signaling, microelectronics and space-borne platforms. Also, it is the first widespread application of the signaling concept Code Division Multiple Access (CDMA). Four or more satellites are required to estimate the location of the user. Medium Earth Orbit (MEO) constellation of 24 satellites was chosen for the realization of GPS. The Department of Defense (DoD) had approved the basic GPS architecture in 1973 but it was declared operational in 1995. The three main segments of GPS system architecture are the space segment, the control segment and the user segment. The space segment consists of orbiting GPS satellites, distributed in six orbital planes, labelled A to F having an inclination of 55° respective to the equatorial plane. The control segment includes a master control station (MCS), a worldwide network of GPS monitor stations and ground control stations. The MCS is based at Colorado Springs, United States. Monitoring satellite orbits and their health, prediction of satellite ephemerides and clock parameters and also updating navigation messages are the major functions of the control segment. Three monitor stations are furnished with ground antennas. They basically upload the information to the GPS satellites. The ground control stations and monitor stations operate distantly from MCS. The observations collected at the ground control stations are processed by the MCS. The processed information includes satellite positions, clock parameters, almanac, atmospheric data and others [1]. The user segment comprises of civilian and military users.

Many commercial GPS receivers are accessible in the market depending on their receiving capabilities and number of tracking channels. With the GPS receiver connected to the antenna, it will be able to estimate the user location. The main difference between the hardware and software GPS receivers is that in hardware receivers, signal processing is performed on a dedicated IC while in a software GPS receiver the signal processing is performed on a general-purpose microprocessor, which in turn allow a huge flexibility in modifying or adding features in the software receivers. Every software receiver requires a small amount of hardware known as front end, which digitizes the signal received from the satellites. Acquisition and tracking of GPS signals are the first two blocks implemented in a software receiver. GPS satellites use two radio frequencies in the L band to transmit signals continuously. They are mentioned as Link 1 (L1) of 1575.42 MHz (f_{L1}) and Link 2 (L2) of 1227.60 MHz (f_{L2}). Apart from these signals, it also transmits navigation data and two digital codes. The navigation data consists of information about orbits and the spreading sequence consists of coarse acquisition code (C/A-code) and encrypted Precision code (P-code). Each space vehicle transmits its own distinctive code.

There are many factors that affect the GPS signals as it propagates. These comprise the ionospheric delay, tropospheric delay, multipath effect and clock errors of the satellite clock. Among these, the effect of propagation of GPS signal through the ionosphere is considered to be predominant [2]. Ionospheric scintillation is mainly due to the irregularities in the density of ions found in the ionospheric layer which can cause fluctuations in amplitude and phase of GPS signals. This

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can even cause the drop of received signal below the acquisition threshold thereby cause cycle slips due to the loss of lock by the receiver's phase lock loop.

GPS SIGNAL CHARACTERISTICS

The GPS signal structure includes RF sinusoidal signals (f_{L1} or f_{L2}) and binary codes. The binary codes (or Pseudo Random Noise (PRN) codes) are Coarse Acquisition (C/A) and Precision (P) codes. Every satellite transmits a distinctive C/A code on L1 and a unique P code on both L1 and L2. The C/A code consists of chips (stream of binary ones and zeros). It is generated by combining the two Gold codes, G1 and G2 (each 1,023 bits). A ten-stage linear shift register driven by a 1.023 MHz clock is used to generate G1 and G2 [3]. Bi phase modulation is used both in L1 and L2 carrier thereby the phase of the carrier shifts by 180° whenever the code value changes from one level to another. Table-1 gives the characteristics of the binary codes. The navigation data is arranged in 25 frames where each frame consists of 5 subframes. Subframes 1, 2 and 3 (the satellite ephemeris and clock parameters) are updated every 30 seconds while subframes 4 and 5 are repeated every 12.5 minutes. The navigation message is transmitted at 50bps (bits per second) with a bit duration of 20ms. It comprises of information on the satellite clock corrections, ephemeris parameters, ionosphere model parameters, almanac and health status of satellites.

Table-1. Characteristics of binary codes.

Characteristics	Binary codes	
	C/A code	**P code**
Number of chips	1023	~ 10 14
Chipping rate	1.023 MHz	10.23 MHz
Chip width	300 m	30 m
Repeats after	1 ms	266 days

In order to obtain information from the GPS signals, the receiver tries to duplicate the transmitted signal. It then tries to align with the incoming signal. The L1 and L2 signals transmitted by the nth satellite can be modelled as

$$S_{L_1}^{(n)}(t) = A_{cq}\, x^{(n)}(t)\, D^{(n)}(t)\, \cos\left(2\pi f_{L_1} t + \theta_{L_1}\right) + A_{pc1}\, y^{(n)}(t)\, D^{(n)}(t) \sin\left(2\pi f_{L_1} t + \theta_{L_1}\right) \quad (1)$$

$$S_{L_2}^{(n)}(t) = A_{pc2}\, y^{(n)}(t)\, D^{(n)}(t)\, \sin\left(2\pi f_{L_2} t + \theta_{L_2}\right) \quad (2)$$

where $S_{L1}^{(n)}(t)$ and $S_{L2}^{(n)}(t)$ represents L1 and L2 signals respectively, A_{cq} is the amplitude of C/A code, A_{pc1} and A_{pc2} is the P code of L1 and L2 signals respectively, $x^{(n)}$ and $y^{(n)}$ are the bit representations of C/A and P code sequences assigned to satellite number n; $D^{(n)}$ indicates the navigation data bit stream; f_{L1} and f_{L2} are the carrier frequencies corresponding to L1 and L2 respectively; Θ_{L1} and Θ_{L2} are the phase associated with L1 and L2 respectively.

The carrier is modulated by binary code as shown in equation (1) and (2). This helps the signal energy to be spread over a wide frequency band than concentrated over a single frequency. The C/A code is spread over 2 MHz and P code over 20 MHz centered at the carrier frequency [4].

GPS SOFTWARE RECEIVER

The software-based GPS receiver consists of both hardware and software parts [5]. Figure-1 presents the schematic of GPS receiver. The received GPS signal cannot be used directly for signal processing. Hence before processing the signal needs to be conditioned. The hardware part does the signal conditioning which includes filtering, amplifying and reducing the frequency down to intermediate frequency. The signal is filtered using band pass filters, amplified using the low noise amplifiers and frequency is translated to intermediate frequency using down converters. Then finally the analog to digital converter is used to transform analog signal to digital signal.

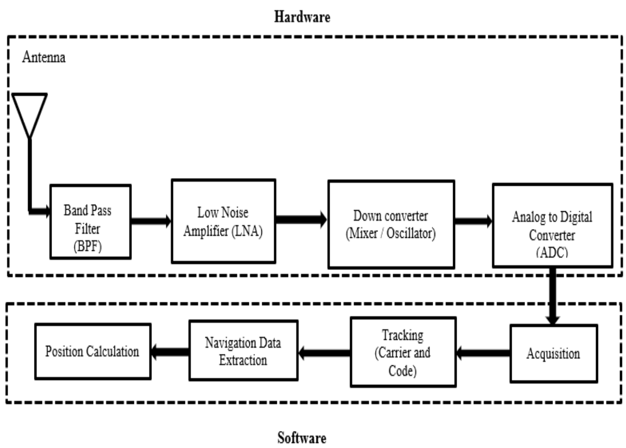

Figure-1. Schematic of GPS receiver.

The signal processing is implemented in the software part. The digitalized GPS signal goes through the acquisition stage, followed by the tracking stage which includes tracking of code and carrier. Further, navigation data decoding and pseudo range estimation are performed in the receiver.

METHODOLOGY

The methodology followed for both the acquisition and tracking stage is described in this section.

Acquisition of GPS Signal

The signal processing of the digitized GPS signal is based on a multi channelized structure. In order to allocate the channel, the receiver needs to know the satellites which are visible to it. There are two ways of

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obtaining it - warm start and cold start. Warm start is when the receiver uses an algorithm which combines the positions of the satellites present in the stored almanac data with the position of the receiver. While the cold start is when the receiver does not take the almanac data. It searches for the satellites which are visible to it. Hence compared to warm start, the cold start method takes a longer time to lock the satellites visible to the receiver. The acquisition stage also determines the doppler frequency and the code delay. Though all the satellites transmit frequency of 1575.42 MHz (L1 band), the received frequency will be different due to the doppler shift. For stationary receiver the doppler shift can never exceed 5KHz. It can go up to 10KHz if the satellite and the user are moving at maximum velocity [6]. The code delay determines the point where the C/A code begins.

The acquisition process includes an acquisition search space which is a two-dimensional search having code delay and doppler frequency as the horizontal and vertical axis respectively. The axes are subdivided into "bins". Each cell in the bin represents a combination of code delay and doppler frequency [7-8]. This two-dimensional search can be implemented using algorithms in the time domain or frequency domain. The serial search [9], parallel frequency space search and parallel code phase search are some of the software-based acquisition algorithms used for implementing acquisition stage. When compared with the other two algorithms parallel code phase search requires less execution time as this algorithm performs acquisition with a smaller number of repetitions [10]. Figure-2 shows the implementation of acquisition of GPS L1 signal using parallel code phase algorithm.

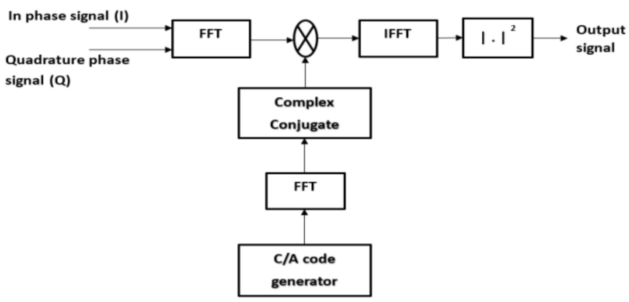

Figure-2. Parallel code phase acquisition algorithm.

The I and Q signal component shown in the block diagram is obtained by determining the product of the incoming signal and the locally generated cosine wave and sine wave (90 ° phase shift of cosine wave) respectively. The complex signal formed by combining these two signals is given as input to the FFT. The frequency domain of locally generated C/A (PRN) code is obtained and further the complex conjugate of the resulting signal is performed. Product of the frequency component of complex signal and complex conjugate of PRN code is performed (the circular correlation between the input signal and the PRN code) [11]. The inverse Fourier Transform of the signal is obtained in order to convert it to time domain. The magnitude of the signal gives the correlation of the incoming signal and the C/A code and is further used for comparing with the threshold value.

Tracking GPS Signal

The basis of the tracking stage is to follow the incoming signal and provide information of the navigation data. The coarse values of the frequency and code obtained in the acquisition stage is proceeded to the tracking stage. In order to track the carrier frequency and the C/A code of the GPS signal two independent loops are used - carrier loop and code loop [12] respectively as shown in Figure-3. The code loop or the Delay Lock Loop (DLL) block diagram forms the top part of Figure-3. The local carrier generator generates the sine and cosine carrier signal. The PRN code generator generates early replica (E), prompt replica (P) and late replica (L) of ½ chip spacing. These three replicas are multiplied with the baseband incoming signal. The output is then integrated for a fixed time (correlator output) which is then used to indicate the amount of correlation between the incoming signal and the locally generated code replica. Figure-4 shows an example of the locked code loop with the prompt replica.

The highest correlation is achieved when the input signal is perfectly coinciding with the prompt replica.

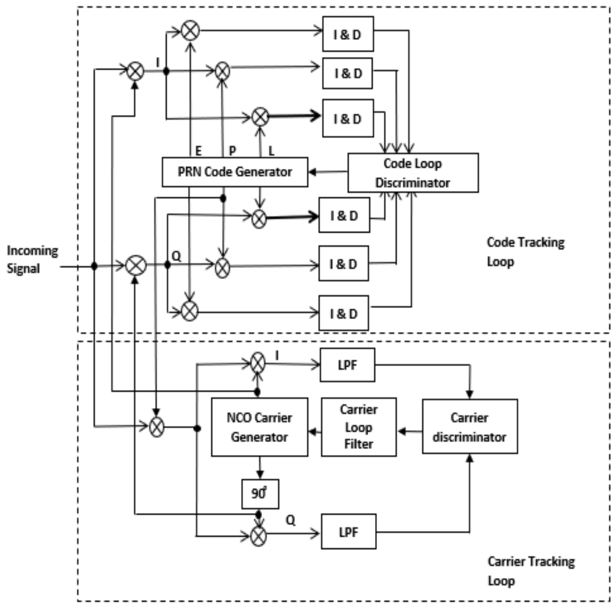

Figure-3. A typical GPS signal tracking block diagram.

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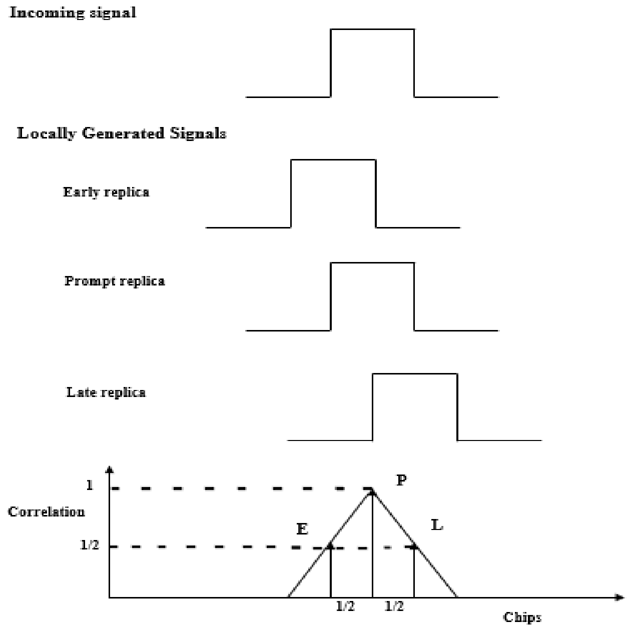

Figure-4. Code loop locked with the prompt replica.

The correlator output is then passed through the DLL discriminator. The DLL discriminator algorithm can be divided into two categories - coherent and non-coherent. In coherent type, the PLL of the carrier loop needs to be in lock whereas the non-coherent DLL is independent of carrier loop. So, non-coherent DLL is mostly preferred when compared to coherent [13]. It provides feedback to the PRN code generator to adjust the code phase of the code replicas (early, prompt and late). Normalized early minus late power DLL discriminator is implemented here. It is described as

$$D = \frac{\left(E_i^2 + E_q^2\right) - \left(L_i^2 + L_q^2\right)}{\left(E_i^2 + E_q^2\right) + \left(L_i^2 + L_q^2\right)} \tag{3}$$

where the six correlator outputs are Ei, Eq, Li and Lq are as shown in Figure-3. The performance of DLL depends on many parameters like correlation spacing, discriminator, NCO sensitivity and DLL loop filter bandwidth.

The carrier tracking loop or Costas loop is modelled as shown in the bottom half of Figure-3. The aim of Costas loop is to determine the exact carrier replica and thereby demodulate the navigation data successfully. Costas loop is preferred to PLL as it is insensitive to bit transitions present in the navigation data. It also tries to sustain all the energy in inphase arm (I). In carrier tracking loop, a process called code wipe off is performed where the product of the input signal and the prompt code replica from the DLL is obtained, which results in code removed from the signal. This signal is then multiplied with the signals produced from the numerically controlled oscillator (NCO). There are further two multiplications involved in the Costas loop. The multiplication between the incoming signal and the locally generated signal along the inphase arm yields,

$$D^s(n)\cos(\omega_{IF}n)\cos(\omega_{IF}n+\phi) = \frac{1}{2}D^s(n)\cos\phi + \frac{1}{2}D^s(n)\cos(2\omega_{IF}n+\phi) \tag{4}$$

and the product of the incoming signal and the 90° phase shifted carrier signal along the quadrature phase arm (Q) yields,

$$D^s(n)\cos(\omega_{IF}n)\sin(\omega_{IF}n+\phi) = \frac{1}{2}D^s(n)\sin\phi + \frac{1}{2}D^s(n)\sin(2\omega_{IF}n+\phi) \tag{5}$$

Further, the signals in the two arms pass through the low pass filter and yields,

$$I^s = \frac{1}{2}D^s(n)\cos(\emptyset) \tag{6}$$

$$Q^s = \frac{1}{2}D^s(n)\,sin(\emptyset) \tag{7}$$

The I ^{s} and Q ^{s} signals then pass through the discriminator. The carrier loop discriminators can be divided into two categories - coherent and non-coherent type. Non coherent type is preferred as it is insensitive to bit transitions [14]. The arctangent discriminator is implemented here. The discriminator tries to reduce the reduce the phase error. Using equations (6) and (7), the phase error (φ) can be determined as

$$\frac{Q^s}{I^s} = \tan(\phi) \tag{8}$$

$$\phi = \tan^{-1}\left[\frac{Q^s}{I^s}\right] \tag{9}$$

In order to make the phase error $\phi = 0$, it is clear from equation (9) that the PLL tries to keep the energy along the in-phase arm maximum and the energy along the quadrature arm minimum. The discriminator implemented here is the arctangent discriminator. The discriminator output is then filtered to estimate doppler frequency. The performance of the PLL depends on the discriminator kind, integration time of the I & D filter, loop filter, and NCO sensitivity [15].

GPS L1 C/A SIGNAL ACQUISITION AND TRACKING SIMULATION RESULTS

The acquisition and tracking of GPS L1 signal using software GPS receiver is implemented using MATLAB. The sampling frequency and IF frequency used is 26 MHz and 6.5 MHz respectively.

Acquisition Result

Acquisition stage is implemented using parallel code phase algorithm and the parameters used are doppler step of 500 Hz and doppler frequency range of +/- 10KHz.

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Figure-5 shows the Space Vehicle (SV) number of the acquired and not acquired satellites. It can be observed that ten satellites are acquired using the acquisition algorithm.

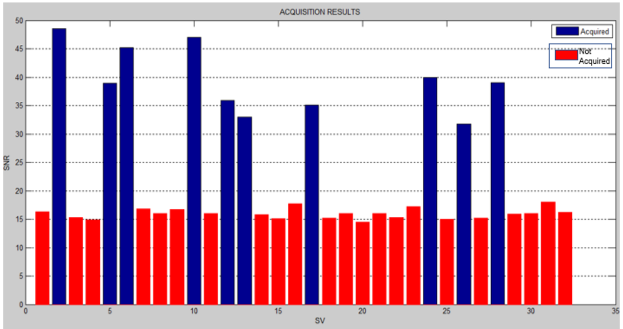

Figure-5. Acquired satellites and not acquired satellites.

Table-2 shows the acquired SV, code phase, doppler frequency and Signal to Noise Ratio (SNR).

Table-2. Acquisition output.

SV	SIGNAL TO NOISE RATIO (SNR)	CODE PHASE (Chip)	DOPPLER FREQUENCY (Hz)
2	48.58	22415	310
5	38.97	16604	-3065
6	45.24	10349	2375
10	46.97	20281	-1035
12	35.89	23492	-3085
13	32.93	3387	520
17	35.13	6347	810
24	39.91	16303	-800
26	31.76	588	645
28	39.08	18741	1675

Tracking Result

Tracking stage is implemented using code loop and carrier loop. The code phase and the doppler frequency obtained from the acquisition stage is used in the tracking algorithm. The parameters used for the implementation of code loop are correlator spacing of 0.5 chips, noise bandwidth of 1 Hz, DLL damping factor of 0.707 and DLL gain of 0.1. The parameters used for the implementation of carrier loop are noise bandwidth of 20 Hz, PLL damping factor of 0.707 and PLL gain of 0.25. Figure-6 and Figure-8 shows the discrete time scatter plot of In phase prompt signal (I p) and Quadrature phase prompt signal (Q p) for Space Vehicle 2, 5, 6, 10, 12, 13, 17, 24, 26 and 28 respectively. Figure-7 and Figure-9 shows the In phase and Quadrature phase prompt signal tracking plot for Space Vehicle 2, 5, 6, 10, 12, 13, 17, 24, 26 and 28 respectively. It is clearly seen from Figure-7 and Figure-9 that the in-phase arm has the navigation data while the quadrature arm has noise.

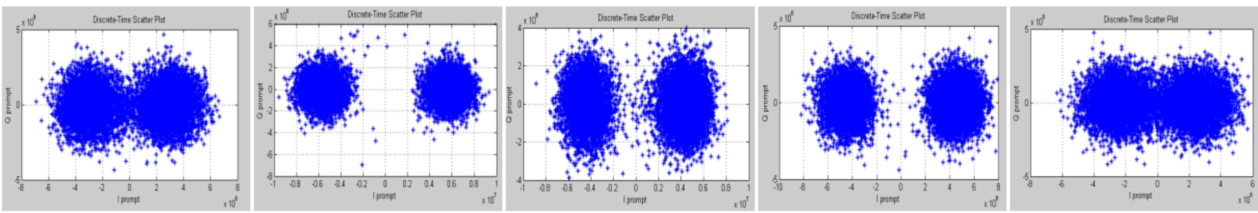

Figure-6. Discrete Time Scatter Plot of Space Vehicle 2, 5, 6, 10, 12 and 13 respectively.

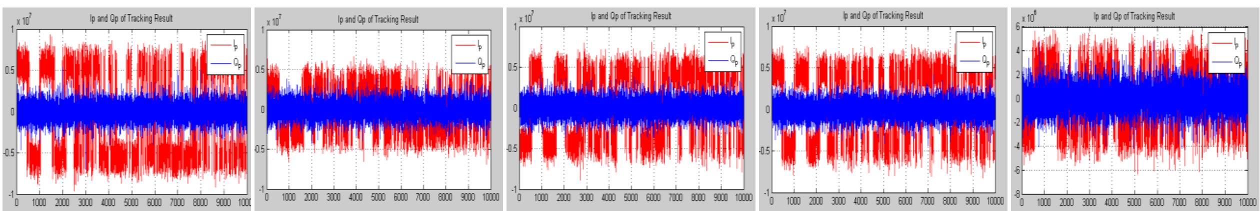

Figure-7. I $_P$ and Q $_P$ tracking plot of space vehicle 2, 5, 6, 10 and 12 respectively.

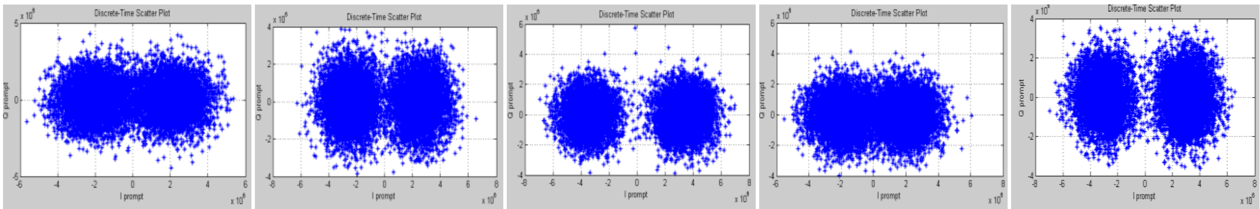

Figure-8. Discrete Time Scatter Plot of Space Vehicle 13, 17, 24, 26 and 28 respectively.

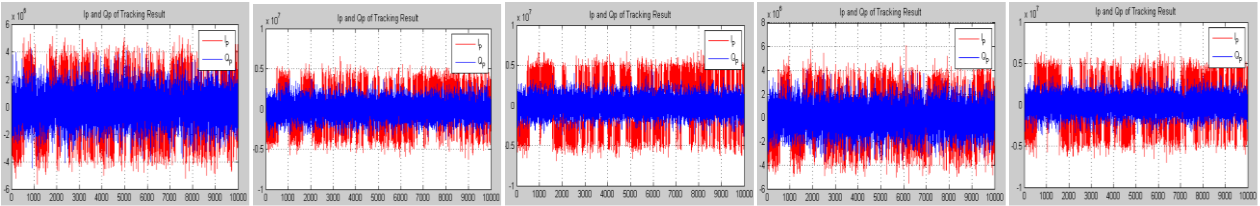

Figure-9. I $_P$ and Q $_P$ tracking plot of space vehicle 13, 17, 24, 26 and 28 respectively.

CONCLUSIONS

In this paper the implementation of the acquisition and tracking of GPS L1 C/A signal is performed using software receiver. The acquisition phase is implemented using parallel code phase algorithm. By employing parallel FFT the acquisition will be very fast at the cost of the complexity involved. The tracking phase is implemented using DLL for code loop and Costas loop for carrier loop. The MATLAB simulation results demonstrate reliable acquisition and tracking. The software GPS receiver also provides a platform for new algorithms to be implemented for various stages in the hardware GPS receiver.

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