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GPS Receiver Simplification for Low-cost Applications and Multipath Mitigation Analysis on SDR-based Re-configurable Software Receiver

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ABSTRACT

Many modern position-based applications rely heavily on the Global Navigation Satellite System (GNSS). Most applications require precise position data obtained through sophisticated hardware with a high computational capacity in the receiver. Some cost-effective applications may not require precise position data and require less complex signal processing. The use of efficient hardware and signal processing techniques to reduce the overall cost of a GNSS receiver is an active research topic. This paper considers Global Positioning System (GPS) constellation and proposes two factors to reduce the receiver complexity: sampling frequency and the number of tracking channels. A Keysight GNSS signal generator to record GPS signals, a Software Defined Radio board and a software-based GPS receiver are used in the experimentation. The sampling frequencies are 40, 20, 10 and 5 MHz considered, and tracking channels are reduced from 12 to 6 and then 4. The increase of error in the receiver position with 6 and 4 satellites is considerably small, but the number of tracking channels and signal processing requirements are reduced considerably. The GPS signals are affected by many errors; one of the significant sources of error is multipath propagation. Three distinct GPS multipath scenarios are generated for four satellite signal combinations with the GNSS simulator for the receiver performance analysis. Three multipath mitigation techniques, namely Early Minus Late (EML), Narrow correlator (NC) and strobe correlator (SC) methods, are considered because of their simple structure and fewer signal processing requirements. The error reductions of three multipath scenarios are compared, and the SC method performs better in all three multipath scenarios.

Keywords: Low-cost GPS receiver; GPS software receiver; Multipath mitigation; Discriminator function design; Multipath scenario parameters

1. INTRODUCTION

Global Navigation Satellite System (GNSS) has become a key component of numerous location-based services, with its vast range of applications. Robust signal processing in GNSS makes obtaining more accurate position information possible. However, the GNSS receiver's performance is significantly hampered in challenging environments (e.g. densely populated urban areas)[1]. The performance and cost of GNSS receivers are influenced by a range of factors such as antenna type, front-end module (Low Noise Amplifier (LNA) capabilities, bandwidth, sampling rate, Analog to Digital Converter (ADC) bit width), acquisition type, the number of tracking channels, type of Delay Locked Loop (DLL) and Phase Locked Loop (PLL)/ Frequency Locked Loop (FLL), position estimation algorithm, etc[2-4]. Some of the cost-effective applications may not require highly accurate position information.

Tracking operation in GNSS receivers occurs in a parallel manner. Therefore, as the number of tracking channels increases, so do the hardware requirement and computational complexity[3]. Fundamentally, GNSS requires a minimum of four satellite signals to calculate user position[5]. The sampling frequency of a GNSS receiver has a significant role in signal processing handling capabilities. Higher sampling frequency entails more sophisticated signal processing modules. Reducing the sampling frequency allows cost-efficient modules to perform signal processing operations for low-cost GNSS receivers[2]. Based on the application, different methodologies are studied to reduce the cost of the GNSS receiver; the paper[3] proposed a miniaturised lightweight, low cost and low-power GPS receiver design, which operated by a single coin cell for the duration of two years. The energy consumption is reduced by offloading the position calculation to the cloud, eventually reducing the hardware complexity.

GNSS satellite signals encounter numerous propagation errors as they travel toward the receiver antenna. The most common error components are ionospheric and tropospheric delays, clock and multipath errors[1]. Most of the errors can be corrected by studying the repeating patterns over time and precise modelling errors. Most signals transmitted from the satellites reach the receiver directly, also known as Line Of Sight (LOS) signals. Still, some errors are due to reflections from local surroundings (buildings, trees, etc.), called multipath propagation, which are challenging to model. The reflected signal with a delay of more than 1.5 chips can be eliminated

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by the correlation properties of the Coarse Acquisition (C/A) code[6-7]. The real problem arises when the LOS and reflected signal delays are comparable. The reflected signals superimpose on the LOS signal and distort its amplitude, code and carrier phase characteristics[1]. As a result, unwanted bias is introduced into delay measurements, manifesting as inaccurate pseudo-range values and incorrect output position[8]. Multipath mitigation techniques are majorly classified into two categories: separation and estimation. The separation-based techniques like Early Minus Late (EML), Narrow Correlator (NC) and Strobe Correlator (SC) are mainly designed to separate LOS signals and multipath signals. These methods aim to track only the LOS signal and thus reduce or eliminate multipath effects. On the other hand, estimation-based techniques like Multipath Estimating Delay Locked Loop (MEDLL), Multipath Mitigation Technique (MMT) and Vision Correlator (VC). These methods intended to provide a rough approximation of the combined effect of the LOS and Multipath signals on the tracking errors by estimating their parameters[7]. These methods work based on the principle of maximum likelihood (ML) estimation and use a correlator array to determine the parameters of both LOS and multipath signals that are combined appropriately[9]. These estimation-based approaches have the drawback of needing many correlators, higher sampling rates, and wider bandwidths. These, in turn, increase system complexity and computational costs[9-11]. In this paper, the main aim is to reduce the receiver complexity and cost. The separation-based methods use few correlators compared to estimation-based methods, are easily implemented, and are independent of the number of reflected paths[11].

In GNSS research, live satellite signals are not appropriate to use due to several reasons. GNSS signals are both time and location dependent. Especially in multipath error analysis, it is difficult to define the number of reflected paths and their exact multipath parameters[12]. The repeatability of a specific scenario is challenging. On the other hand, a GNSS simulator can provide more flexibility and reconfigurability, allowing users to introduce errors with user-defined parameters and signal strengths. Simulators can construct required test scenarios for user-defined locations and dynamics. The significant advantage of using simulated signals is that the user can turn on or off the specific error as per the requirement[12-14]. Application-specific integrated circuits are used to implement the functions of traditional hardware-based receiver processing. Software-based receivers offer greater flexibility and enable the implementation of more complex algorithms than their hardware-based counterparts. Because of this, software-defined GNSS receivers have attracted much interest from the research and development communities over the past few years. A software-based GNSS receiver is more suitable for implementing algorithms and analysing receiver performance under specific error conditions[15-17]. The standard GNSS simulator outputs an RF signal; however, it must be converted to digital format to access the generated signal with a software receiver. Software-Defined Radio (SDR) is a technology undergoing rapid development while garnering much attention and generating widespread interest in the receiver industry. SDR technology aims to create a receiver with an open architecture and flexible capabilities. Building re-configurable SDRs allows the dynamic selection of parameters for individual modules[18]. The SDR board converts RF signals to complex data samples in IQ format, which can be used with the software-based receiver any number of times[2].

2. GPS RECEIVER SIMPLIFICATION

In GPS receivers, the computational complexity and hardware requirement depend on several factors, which eventually increase the cost, as discussed in Section.1. To reduce the overall cost of the receiver, this paper focuses on two factors: sampling frequency[4] and the number of tracking channels[3,19].

Most receivers processes over-sampled data, usually a few tens of MHz[3], which can better measure the signals, but the signal processing requirements increase. Unlike in wireless communications, the sampling rate in a GPS plays a significant role in pseudo-range measurements. In this paper, different sampling rates considered are 40, 20, 10 and 5 MHz, and the effect on the final output position of the receiver is compared. This paper has attempted to use a low sampling frequency signal of 5 MHz as per the analysis given in[4]. If the sampling frequency is reduced further based on the Nyquist theorem, the signal can still be reconstructed[4], but the error in the pseudo-range gets increases[20].

In real-time GPS receivers, the tracking process runs in parallel for all satellites (as per the maximum channel capability of the receiver), and the discriminator function estimates the delay values for each tracking channel in parallel. As the number of satellite signals increases, so does the signal processing and hardware requirement[3]. Reducing the satellite signals with suitable Dilution Of Precision (DOP) does not cause much accuracy degradation[19]. A software-based GPS receiver is used to study the effect of reducing the number of satellites for position calculations. The recorded simulator data is for 12 GPS satellites. In the experiments, variation in latitude and longitude information is observed by reducing the number of satellites based on good satellite geometry, i.e., DOP values.

The satellite selection criteria are based on the DOP value for a particular combination of satellites. A satellite constellation's geometry has a significant impact on positioning accuracy[5]. The position of the satellites solely determines DOP: how many satellites are visible, how high they are in the sky, and the bearing on them[21], as shown in Fig. 1. This is commonly referred to as geometry. The calculated position can differ depending on which satellites are used for measurement. When the DOP value is low, the solution is more reliable; conversely, when the value is high, it indicates that the satellite geometry and measurement configuration are both suboptimal. The DOP value ranges are classified according to paper[22]: Ideal if >1; Excellent if 1-2; Good if 2-5; Moderate if 5-10; Fair if 10-20; Poor if 20<.

The procedure for calculating DOP values is as follows[5,21]. The most fundamental measurement in satellite navigation is range measurement from satellite to receiver. The receiver

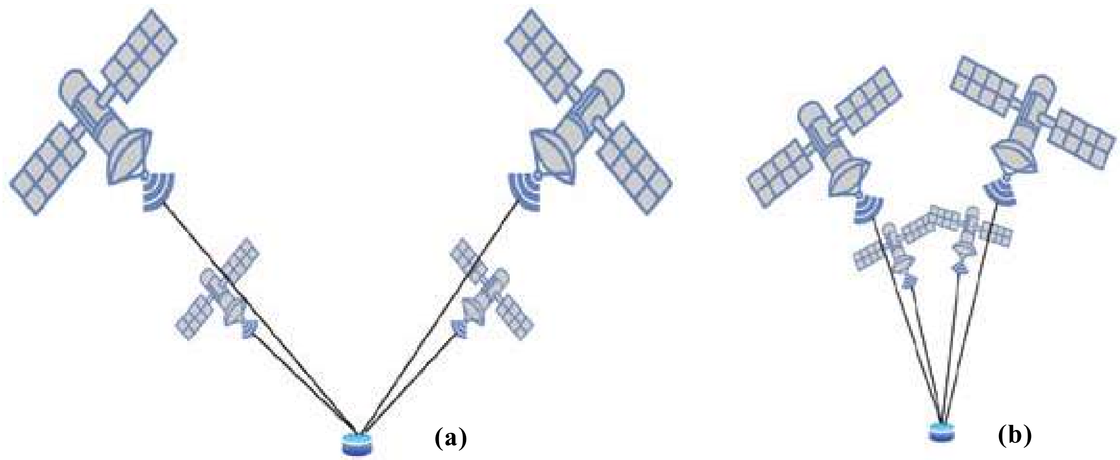


Figure 1. Satellite geometry versus DOP representation[22]: (a) Good DOP and (b) Poor DOP.

clock is not synchronised with the satellite clock; the measured range values are not true range values, hence called pseudo-ranges. The pseudo-range Eqn. is given as[21]

$$PR_i = \sqrt{(X - X_i)^2 + (Y - Y_i)^2 + (Z - Z_i)^2} + ct_B \quad (1)$$

PR_i is the pseudo-range from receiver to i^{th} satellite, X, Y, Z is the receiver-unknown position coordinates, X_i, Y_i, Z_i is the satellite position coordinates. t_B is the receiver clock offset in seconds and c is the speed of light in mtrs/sec.

Fundamental satellite navigation requires a minimum of four satellite signals because of four unknowns X, Y, Z, and time parameter t_B. The pseudo-range equations are nonlinear; after linearisation by Taylor series expansion, the linearised pseudo-ranges equation is of the form[5,21]:

$$\begin{pmatrix} \partial PR_1 \\ \partial PR_2 \\ \partial PR_3 \\ \partial PR_4 \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} & h_{13} & 1 \\ h_{21} & h_{22} & h_{23} & 1 \\ h_{31} & h_{32} & h_{33} & 1 \\ h_{41} & h_{42} & h_{43} & 1 \end{pmatrix} \begin{pmatrix} \partial X \\ \partial Y \\ \partial Z \\ ct_B \end{pmatrix} \quad (2)$$

where, PR_1 is pseudo-range from i[th] satellite, h_{mn} elements represent direction cosines to each of the satellites. The Eqn. can be written in general form[21]

$$\partial Y = H \partial \beta \quad (3)$$

A receiver iteratively updates an initial estimate of β by using $\partial\beta$ until converges. In the last column of the H matrix, all ones show receiver clock offset biases common for all satellite pseudo-range measurements. Consider $\partial\beta$ to be a zero mean vector containing errors in the estimated user state; statistics of $\partial\beta$ provides errors in the expected position. The covariance of $\partial\beta$ is[21]:

$$\mathrm{cov}(\partial\beta) = E[\partial\beta\partial\beta^T] = E[(H^T H)^{-1} H^T \partial\underline{Y}\partial\underline{Y}^T H (H^T H)^{-1}] \quad (4)$$

$$\mathrm{cov}(\partial\beta) = (H^T H)^{-1} H^T \mathrm{cov}(\partial\underline{Y}) H (H^T H)^{-1} \quad (5)$$

The covariance of $\partial\underline{Y}$, as well as the pseudo-range errors, are considered to be Gaussian, uncorrelated random variables. As a result, they are statistically independent, yielding a diagonal covariance matrix. Furthermore, the variance σ_r of the range measurement errors is assumed to be the same for all individual satellites[21].

$$\mathrm{cov}(\partial Y) = I\sigma_r^2 \quad (6)$$

Results in:

$$E[\partial\beta\partial\beta^T] = (H^T H)^{-1} H^T H (H^T H)^{-1} \sigma_r^2 \quad (7)$$

$$\mathrm{cov}(\partial\delta) = (H^T H)^{-1} \sigma_r^2 \quad (8)$$

Let $G=(H^TH)^{-1}$ and $B=ct_B$, then $\mathrm{cov}(\partial\beta) = \sigma_r^2$ G then the Eqn. become[21]:

$$\begin{pmatrix} \sigma_x^2 & \mathrm{cov}\,ar(X,Y) & \mathrm{cov}\,ar(X,Z) & \mathrm{cov}\,ar(X,B) \\ \mathrm{cov}\,ar(Y,X) & \sigma_y^2 & \mathrm{cov}\,ar(Y,Z) & \mathrm{cov}\,ar(Y,B) \\ \mathrm{cov}\,ar(Z,X) & \mathrm{cov}\,ar(Z,Y) & \sigma_z^2 & \mathrm{cov}\,ar(Z,B) \\ \mathrm{cov}\,ar(B,X) & \mathrm{cov}\,ar(B,Y) & \mathrm{cov}\,ar(B,Z) & \sigma_B^2 \end{pmatrix} = \begin{pmatrix} G_{xx} & G_{xy} & G_{xz} & G_{xB} \\ G_{yx} & G_{yy} & G_{yx} & G_{yB} \\ G_{zx} & G_{zy} & G_{zz} & G_{zB} \\ G_{Bx} & G_{By} & G_{Bz} & G_{BB} \end{pmatrix} \sigma_r^2 \quad (9)$$

The elements of G provide a measurement of satellite geometry known as the DOP. The diagonal elements of G can be used to calculate various DOP values[21].

$$\sigma_x^2 + \sigma_y^2 + \sigma_z^2 + \sigma_B^2 = (G_{xx} + G_{yy} + G_{zz} + G_{BB})\sigma_r^2 \quad (10)$$

$$\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 + \sigma_B^2} = GDOP\sigma_r \quad (11)$$

Geometric DOP (GDOP) is defined as[21],

$$GDOP = \sqrt{G_{xx} + G_{yy} + G_{zz} + G_{BB}} \quad (12)$$

Similarly, Positional DOP (PDOP), Horizontal DOP (HDOP), Vertical DOP (VDOP), and Time DOP (TDOP) expressions are given in[5,21].

A GPS receiver with reduced signal processing requirements can be achieved by reducing the sampling rate and the number of channels considered for tracking with good satellite geometry[3-4,19].

3. METHODOLOGY

The GPS signals used in this paper are generated by the Keysight GNSS simulator. The generated RF signals are converted into digital samples by using an SDR board. as shown in the schematic (Fig. 2). In the GNSS RF section; RF signals can be connected to the SDR input port, either actual signals received by an antenna or generated by a simulator. In the case of real-time GNSS signal collection, an antenna-received signal can be fed to the SDR board. This paper uses simulator data to analyse the performance; hence the simulator RF signal is connected to the SDR board.

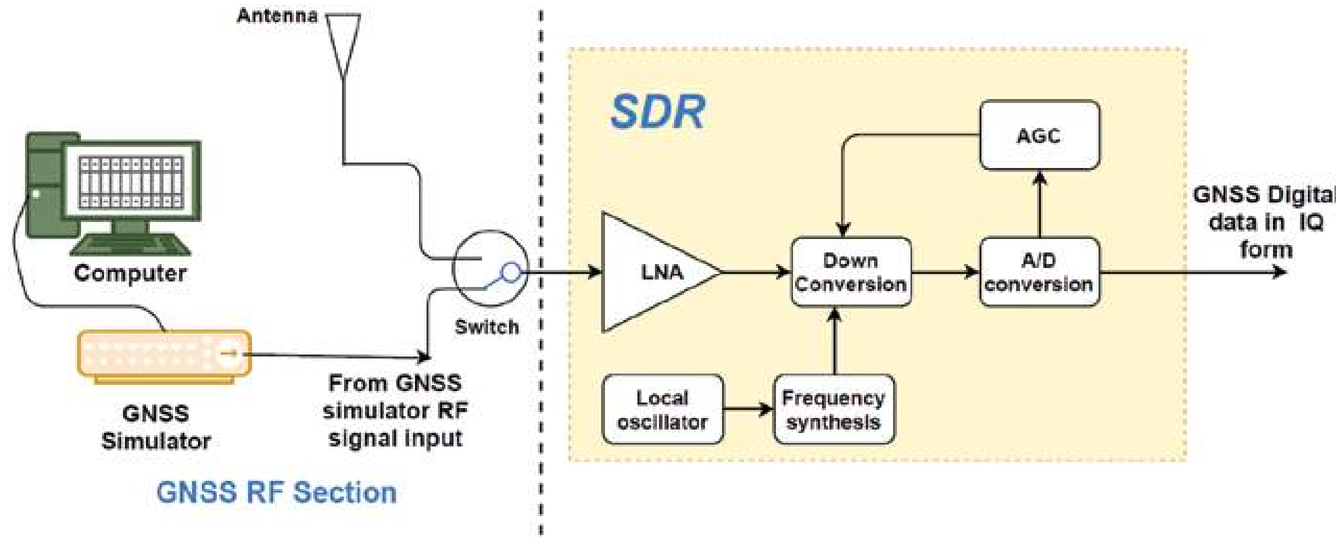
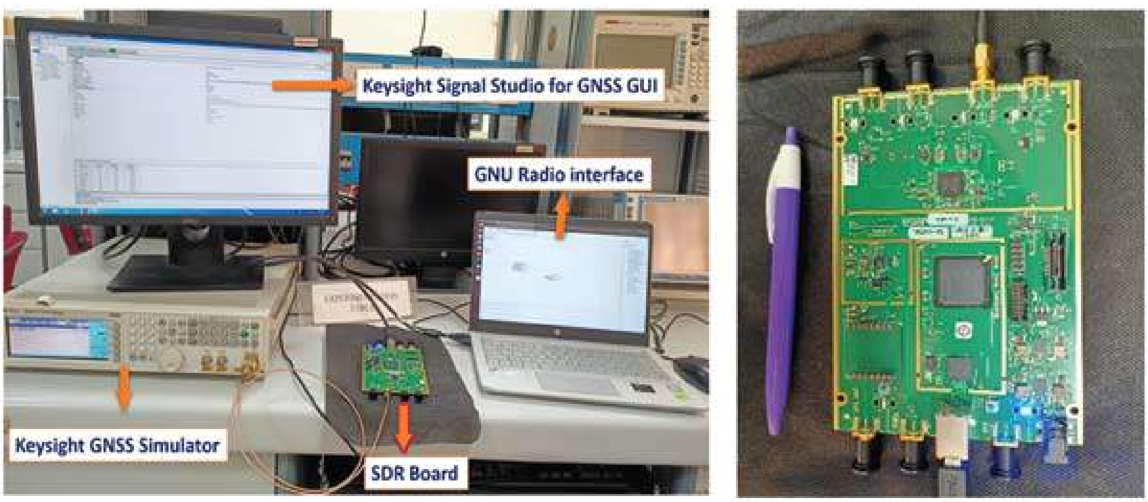


Figure 2. Block diagram of GPS data recording using SDR.



(a) (b)

Figure 3. GPS data recording using SDR board: (a) GPS digital data recording setup, and (b) SDR board.

3.1 GPS Signal Generation With the Simulator and Digital Data Recording Using the SDR Board

The Keysight EXG Vector Signal Generator can generate GPS, GLONASS, Galileo, Beidou, and QZNSS constellations. It is connected to a computer by ethernet cable and is controlled by Keysight Signal Studio for Global Navigation Satellite System software. The simulator generates GPS RF signals when all the required parameters, such as latitude, longitude, time and optional user-defined errors, are entered. GNSS simulators allow the user to generate critical test scenarios defined by the user to analyse receiver performance[14].

A software-based GPS receiver cannot directly use the generated RF signal from the simulator; a digital signal is required. The SDR board converts and records digital IQ samples from RF signals[17]. The Ettus Research USRP B210 SDR board is used since its features match the hardware requirements. The simulator output is connected to the SDR board through a coaxial cable. A block schematic of an SDR operation is shown in Fig. 2. The RF signal is amplified and converted using an LNA. The ADC converts the down-converted analogue signal into digitised IQ data samples[15-16,18,23]; the generated IQ data samples are stored on the host PC via a USB 3.0 interface. The GNURadio tool kit with UHD driver records digitised data in a host computer at a 5 MHz front-end bandwidth with 8-bit complex IQ samples signals power at -70 dBm. The GPS data recording setup is shown in Fig. 3.

3.2 GPS Software-Based Receiver

GPS receiver performance analysis with the software-based receiver is a more convenient approach to evaluate its performance under specific error conditions with repeatable experiments[14,16-17]. The generated digitised signals are used with MATLAB-based GPS software receiver[24], as shown in schematic Fig. 4. The duration of the signal considered throughout the paper is 100 seconds of GPS digitised signal for position calculation. However, to receive a complete set of five sub-frames of GPS and get location output, a signal duration of only 30 seconds is required[5,24]. A parallel code phase search acquisition method is used to acquire available satellite signals and their associated preliminary carrier and code phase values.

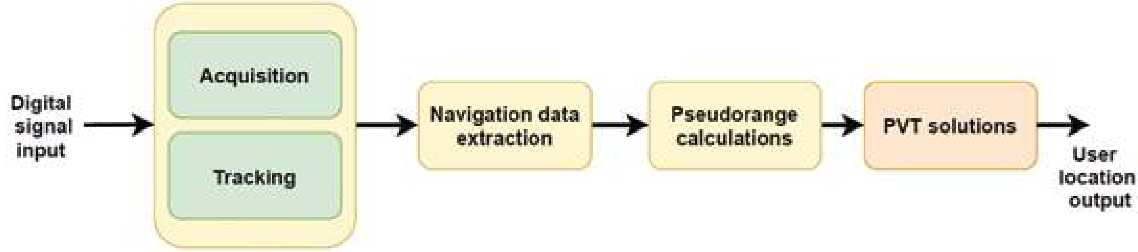


Figure 4. Block diagram of GPS software receiver.

In the tracking stage, the fine carrier phase with PLL and the code phase with DLL are measured[25] to compute pseudo-ranges and doppler values for each tracking satellite. This tracking procedure involves code and carrier wipe-off, and the output bit sequence is navigation bits. The navigation bits are divided into subframes according to the standard subframe structure[26], and satellite ephemeris parameters and timing information are decoded based on subframe bit position. These satellite ephemeris parameters and other parameters are passed to the position estimation stage, where a Least Mean Square based estimator is employed to calculate the receiver position[24].

3.3 Multipath Error and Mitigation Methods

The multipath error occurs when the receiver processes the combined signal as if it were a single path after receiving the direct satellite signal via multiple reflected paths. Multipath error is induced locally where the antenna is prone to receiving reflected signals from nearby objects along with LOS signals. In GPS, multipath causes tracking errors in the receiver, resulting in a range error of up to several meters and inaccurate position output[6].

The GPS RF signals transmitted from the satellite transmitter can be represented in mathematical form as[5,9]

$$T_{xt}(t) = \sum_q \sqrt{E_b} b_q m(t - qT_b) b(t - qT_b) \tag{13}$$

where, b_q ' s are navigation bits, T_b is bit period, $m(t)$ is modulating waveform.

The received GPS signal at the receiver antenna is a distorted version of the transmitted signal[9], as given by Eqn. (13).

$$R(t) = \sum_{k=1}^{M} A_k S(t - \tau_k) e^{j(\phi_k)} + \eta(t) \tag{14}$$

where, A_k, ϕ_k, τ_k, are amplitude, phase and delay for k^{th} path respectively, $\eta(t)$ is additive Gaussian noise.

The main focus of this paper is to design a GPS receiver with less complex, low-cost, with optimum performance. The separation-based multipath mitigation methods are chosen over estimation-based methods to reduce the complexity of the receiver[9]. The correlator spacing in the DLL depends on the front-end bandwidth, and the relationship is given in[8], as shown in Eqn. (15).

$$\text{Correlator spacing} \geq \frac{f_{chip}}{\text{front end bandwidth}} \tag{15}$$

where, f_{chip} is the code chipping rate.

The type of discriminator and correlator spacing determines the code discriminator's behaviour, which significantly impacts the receiver performance under multipath conditions[27].

3.3.1 Early Minus Late Method

The GPS receiver uses a traditional correlation-based code tracking structure based on a feedback delay estimator implemented via a feedback loop[5]. The EML DLL is a feedback delay estimator in which a discriminator function is formed by using two correlators separated by 0.5 to 1 chip as given in[5]; the correlator spacing 0.5 is considered based on Eqn (15). The zero crossings of this function determine the path delays of the received signal[24].

$$Discr_{EML} = \frac{\sqrt{I_E^2 + Q_E^2} - \sqrt{I_L^2 + Q_L^2}}{\sqrt{I_E^2 + Q_E^2} + \sqrt{I_L^2 + Q_L^2}} \tag{16}$$

where, E is denoted for Early and L is denoted for Late correlators position, I indicates In-phase, and Q indicates quadrature measurements.

The conventional EML method is not suitable in closely spaced multipath scenarios. The enhanced EML-based methods are developed to improve the receiver performance under multipath error scenarios.

3.3.2 Narrow Correlator Method

The Narrow Correlator method works based on the principle of reducing the correlator spacing to measure the delay more precisely compared to the EML correlator method[14]. The NC method is based on the observation that the effect of multipath signals on the correlation function is minimal at the peak. Therefore, the effect of multipath can be mitigated by positioning the correlators near the peak. The receiver's front-end bandwidth constraints the narrowing of the correlator spacing. Band limiting round the autocorrelation peak such that the discrimination between early and late correlators is limited when a very narrow correlator is used. As a result, decreasing the spacing between early and late correlators will not be able to reduce the multipath errors infinitely[27]. The spacing between correlators is 0.25 chips based on Eqn. (15).

3.3.3 Strobe Correlator Method

The Strobe Correlator method uses five correlators per channel, i.e. one extra pair compared to EML and NC method are the so-called inner and outer correlators, which perform better in moderate multipath scenario conditions[28]. In the conventional implementation, their distance from one another is double. The discriminator function for the strobe correlator can be given as[28]:

$$Discr_{SC} = 2[R(\tau + \frac{\tau_d}{2}) - R(\tau + \frac{\tau_d}{2})] - [R(\tau + \frac{\tau_{2d}}{2}) - R(\tau + \frac{\tau_{2d}}{2})] \tag{17}$$

where, $R(\tau)$ is the correlation function and, τ_d is the inner

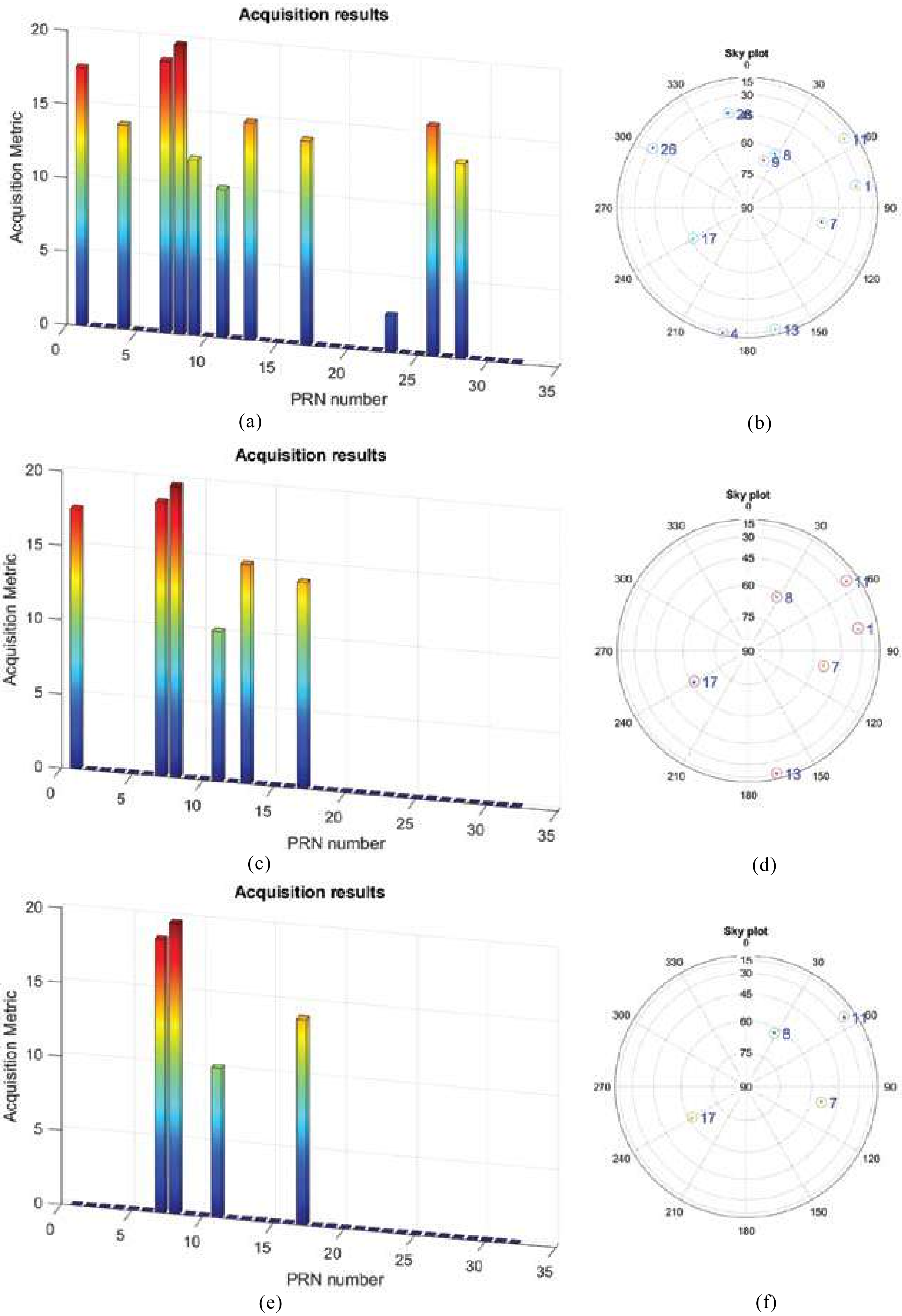


Figure 5. Acquisition and sky plot of different satellite combinations, (a) Acquisition of 12 satellite signals, (b) Sky plot of 12 satellites, (c) Acquisition of 6 satellite signals, (d) Sky plot of 6 satellites, (e) Acquisition of 4 satellite signals, and (f) Sky plot of 4 satellites.

correlator delay 0.25 chips correlator spacing is considered based on Eqn. (15).

4. REDUCING THE SAMPLING RATE AND NUMBER OF SATELLITES AND STUDY OF THE EFFECT ON POSITION ESTIMATION

The paper's main aim is to reduce the complexity of the receiver by reducing the sampling rate and number of satellites tracking without much degradation in accuracy. The GPS signals considered four different sampling rates 40, 20, 10 and 5 MHz for reduced sampling rate and three combinations with the reduced number of GPS satellites from 12, then 6, and then 4 satellite signals are considered.

The sampling rates of GPS satellite signals 40, 20, 10 and 5 MHz are recorded for 70 sec. duration and given as the input for the GPS software receiver and obtained position outputs. The radial error with respect to the input position is calculated; the obtained errors are 3.358, 3.390, 3.412, and 3.680 meters

Table 1. DOP values calculation for different number of satellite combinations

No. of satellites	GDOP	PDOP	HDOP	VDOP	TDOP
12	2.0438	1.8069	1.7149	0.5694	0.9550
6	3.2190	2.7800	2.6068	0.9660	1.6229
4	3.5180	3.1135	2.8142	1.3297	1.6379

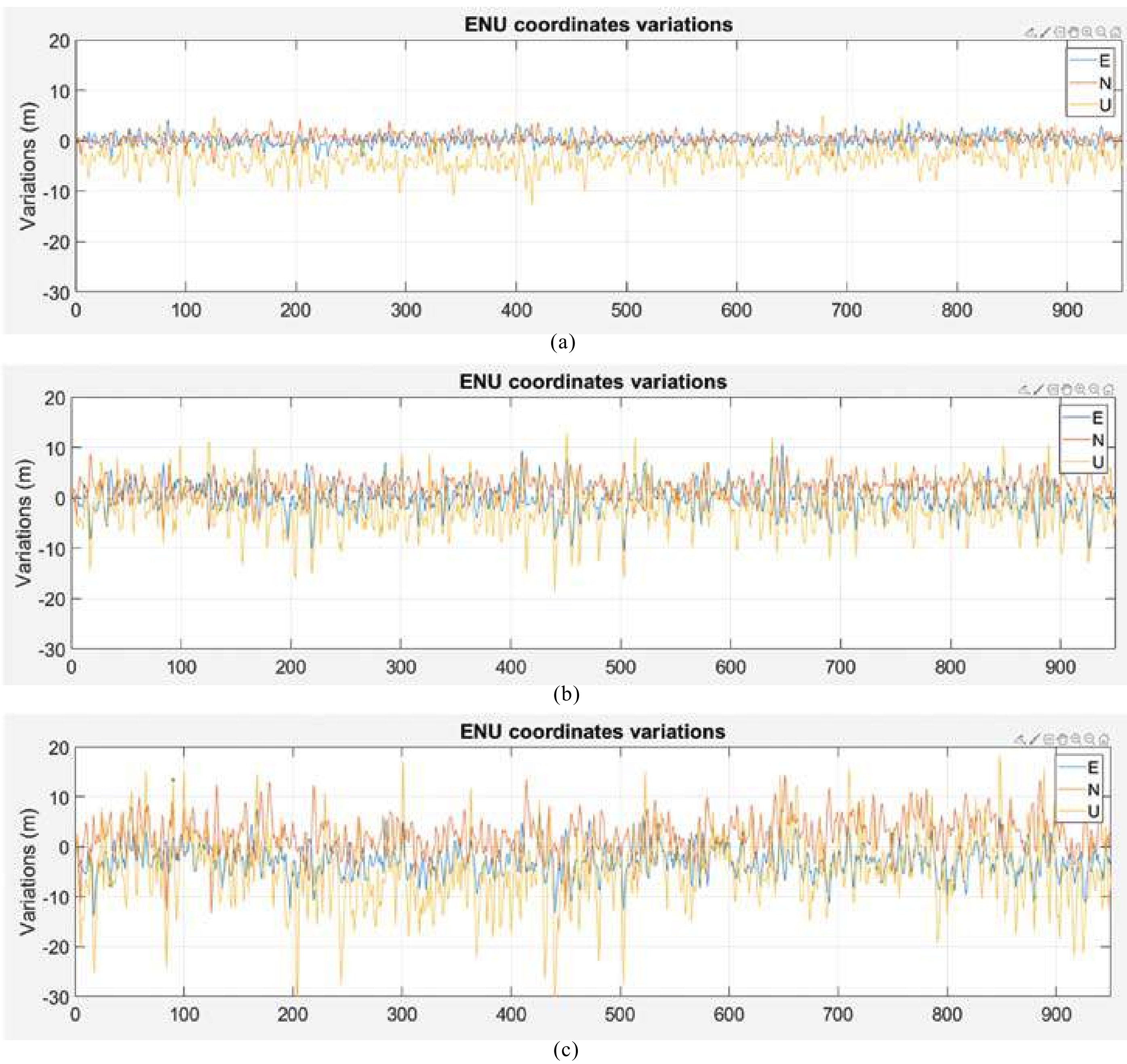


Figure 6. ENU coordinates variations in different number of satellite combinations, (a) 12 satellites combination, (b) 6 satellites combination, and (c) 4 satellites combination.

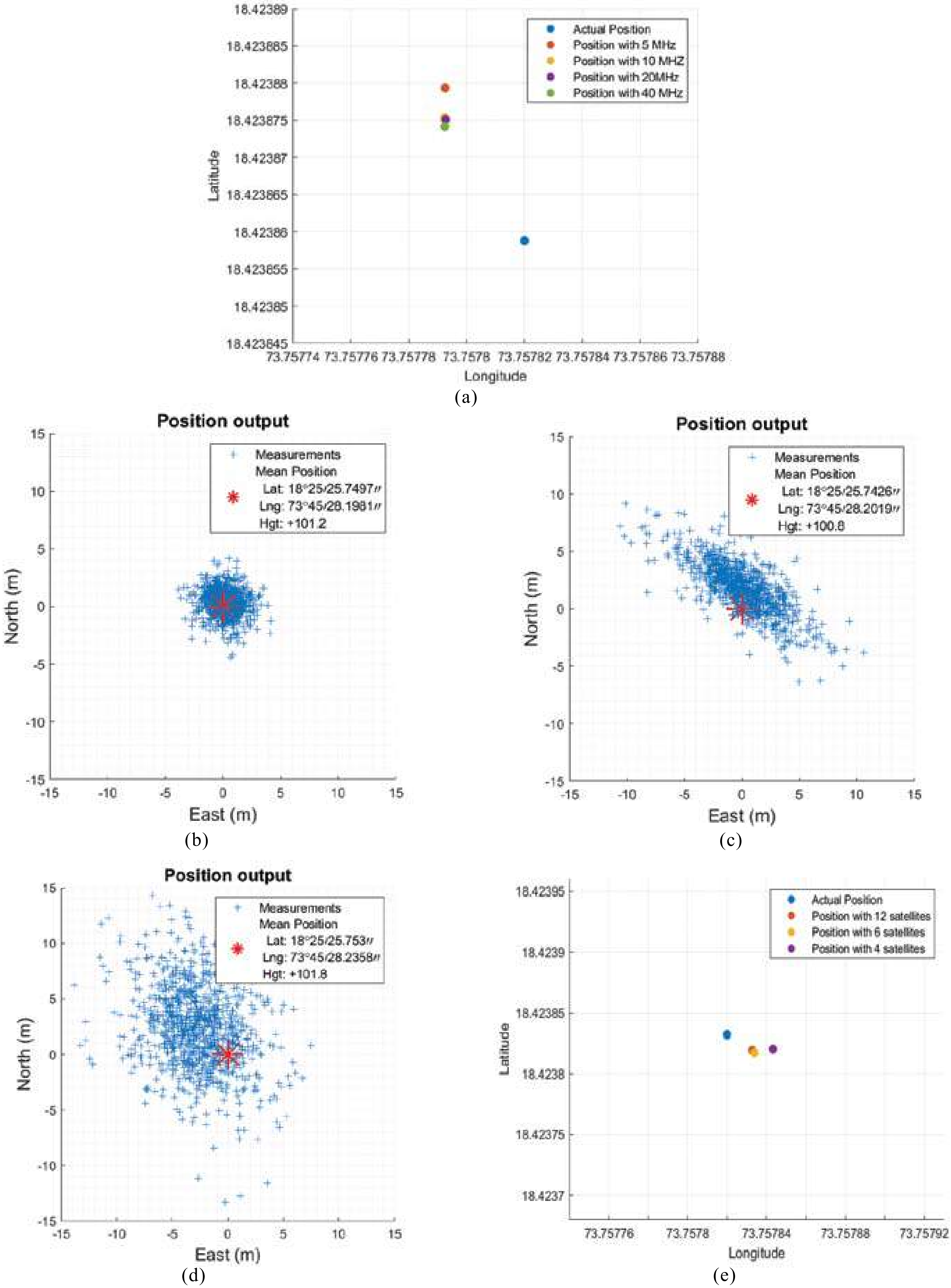


Figure 7. Position output with different sampling rates and reduced number of satellite combinations, (a) Different sampling rate output positions comparision, (b) 12 satellite combination, (c) 6 satellite combination, (d) 4 satellite combination, and (e) Position comparison with different number of satellite combinations.

for 40, 20, 10 and 5 MHz sampling rate signals, respectively. The comparison figure is shown in Fig. 7(a). The sampling rate considered for the reduced number of satellites is 5 MHz.

The combination of satellites when the different number of satellites considered are (i) 12 satellite signals (PRN IDs: 1,2,4,7,8,9,11,13,17,23,26,28), (ii) 6 satellite signals (PRN IDs: 1,7,8,11,13,17) and (iii) 4 satellite signals (PRN IDs: 7,8,11,17) produced minimum DOP values, the obtained DOP values are fall under the good category[22]. The DOP values are calculated based on equations given in[5]. The calculated DOP values for the different number of satellite combinations are tabulated in Table 1.

The different combinations of satellite signals run on a software-based GPS receiver to analyse the effect on accuracy with the reduced satellite signals.

The acquisition and sky plot for a different combination of satellites can be seen in Fig. 5. The acquisition plot shows the acquired satellite signals at corresponding PRN numbers on the X-axis and their signal strengths on the Y-axis. The sky plot shows the satellite position in the azimuth and elevation plots. The sky plot's circles represent elevation angles, while the lines represent azimuth angles.

Figure 6 shows the East North Up (ENU) coordinates variations for different satellite combinations. It can be observed that the ENU variations in the 6 and 4 satellite signals are slightly higher than that of the 12 satellite signals. However, the number of satellites is reduced to half and more than half, respectively.

The different sampling rates on the receiver output positions comparison are shown in Fig. 7(a). The position outputs with different satellite combinations can be seen in Fig. 7(b-e); when the number of satellites is reduced, the measurement spread increases, and slight inaccuracies in the final position. The final position output is the mean position indicated by the red pointer. The position output values are tabulated in Table 2. The error present in each combination with respect to the actual position is calculated. The conversion of latitude and longitude in degrees, minutes and seconds format to distance in meters by the procedure given in reference 29.

Table 2. Receiver output location with different number of satellites

Number of satellites	Latitude	Longitude	Radial error in meters
(Actual i/p position)	18^0 25' 25.7952"	73^0 45' 28.1520"	
12	18^0 25' 25.7497"	73^0 45' 28.1981"	1.949
6	18^0 25' 25.7426"	73^0 45' 28.2019"	2.186
4	18^0 25' 25.7530"	73^0 45' 28.2358"	2.780

The obtained positions for three different numbers of satellite signal combinations are compared with respect to the input position; the comparison plot can be seen in Fig. 7(e); a single point position is an average solution of 100 seconds of data.

From Fig. 7(e), it can be observed that as the number of satellites is reduced, the distance between the estimated and actual positions is slightly increases.

As per the obtained results, choosing the appropriate satellites according to the minimum DOP values shows that the final results are decent for cost-effective receivers. Selecting the best possible DOP values with a four-channel receiver can be achieved by tracking four channels at a time, decoding satellite positions for four satellites and used for initial position calculation. Similarly, two more times, tracking operation for the remaining satellites gives all the 12 satellite parameters, and from these best possible DOP values can be chosen for position calculations. After the third iteration, the best possible DOP value satellite combination is used for position estimation.

5. RECEIVER PERFORMANCE ANALYSIS IN DIFFERENT MULTIPATH (MP) SCENARIOS

GPS position calculations are based on pseudo-range measurements from satellite to receiver. In practical applications, the receiver receives the LOS signal along with the reflected signals. In general, the multipath signal delays are varied from 0 to 1.2 chips concerning the original signal[30]. Wang & Huang defines multipath parameters, and the code delay parameters vary from 0.1 to 1.2. This paper generates three scenarios with different code delay and attenuation parameters.

In this paper, three distinct multipath scenarios are generated with the simulator. In the MP-1 scenario, two satellite signals, PRN IDs 7 and 17, are added with the reflected signal with code phase 0.5 and 0.6 chips, respectively, and satellite signals PRN IDs 8 and 11 are with no multipath. The attenuation for reflected signals is set to -10dB concerning actual signals. In the MP-2 scenario, three reflected paths are generated for the satellite signal PRN IDs 8, 11, and 17, added with code phase 0.4, 0.5, and 0.7 chips, respectively. An attenuation of -10dB is given for reflected signals concerning the actual signal and PRN 7 with no multipath. In the MP-3 scenario, all four satellite signals PRN IDs 7, 8, 11, and 18 are added with the reflected signals with delay parameters are 0.8, 0.7, 0.75, and 0.8 chips, respectively. The reflected path signals attenuation

Table 3. MP scenario generation parameters

Satellite PRN ID	Code phase (Chips)	Attenuation
MP-1 Scenario parameters		
7	0.5	-10dB
8	No Multipath	-------
11	No Multipath	-------
17	0.6	-10dB
MP-2 Scenario parameters		
7	No Multipath	-------
8	0.4	-10dB
11	0.5	-10dB
17	0.7	-10dB
MP-3 Scenario parameters		
7	0.8	-10dB
8	0.7	-10dB
11	0.75	-10dB
17	0.8	-10dB

Table 4. Receiver output with different methods in generated MP scenarios

Method	Latitude	Longitude	Radial error in meters	Per cemt of error reduction compared to EML
Actual i/p position	18^0 25' 25.7952"	73^0 45' 28.1520"		
		MP-1 Scenario position outputs		
EML	18^0 25' 26.2899"	73^0 45' 27.5059"	24.33	-------
NC	18^0 25' 26.1134"	73^0 45' 27.7538"	15.26	37.27
SC	18^0 25' 25.9185"	73^0 45' 28.0058"	5.73	76.44
		MP-2 Scenario position outputs		
EML	18^0 25' 24.9676"	73^0 45' 29.4746"	46.43	-------
NC	18^0 25' 25.1649"	73^0 45' 28.9012"	29.34	36.80
SC	18^0 25' 25.3229"	73^0 45' 28.3002"	15.22	67.21
		MP-3 Scenario position outputs		
EML	18^0 25' 25.6709"	73^0 45' 28.2706"	5.179	-------
NC	18^0 25' 25.7256"	73^0 45' 28.2337"	3.218	37.86
SC	18^0 25' 25.7597"	73^0 45' 28.2148"	2.142	58.64

is given by -10 dB compared to actual signals. Multipath scenario parameters are given in Table 3.

The output positions of the software GPS receiver for three different multipath scenarios is tabulated in Table .4. Three different techniques outcomes are compared with the actual input position information. The error present in each method is compared and tabulated results.

The difference between the actual and obtained positions is converted into meters. The percentage of error reduction compared to the basic EML method in three multipath scenarios are tabulated in Table 4. In the case of the MP-1 scenario, results show that the NC method can reduce 37.27 per cent, and the SC method can reduce 76.44 per cent concerning the basic EML method. In MP-2, the percentage of error reduction compared to the standard EML method with the NC method is 36.80 per cent, and with the SC method is 67.21 per cent. In the MP-3 case, the percentage of error reduction compared to the standard EML method with the NC method is 37.86 per cent, and with the SC method is 58.64 per cent. The SC method results show improvement in error reduction compared to EML and NC methods.

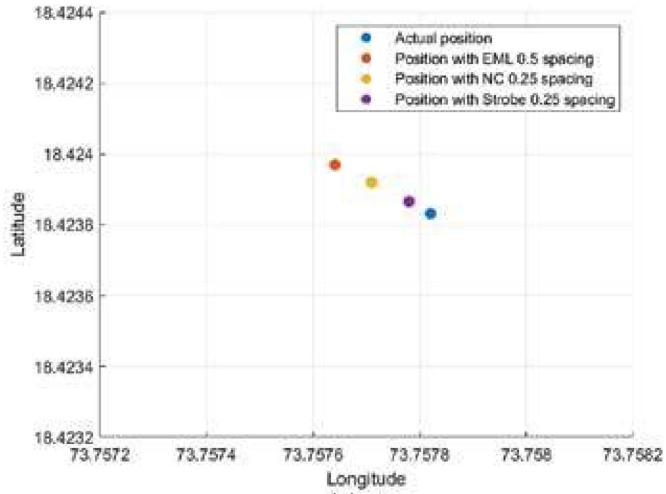
In Fig. 8, the output positions with three different methods are plotted for comparison; each point represents the average point position calculated for 100 sec. of information. From Fig. 8, it can be observed that the position obtained by the SC method is closer to the actual position compared to NC and EML methods in all three distinct simulator-generated multipath scenario cases.

In the discriminator function-based methods, the strobe correlator method performs better in error reduction than EML and NC methods in three different scenarios. The SC method comes under a double-delta tracking scheme, which uses two pairs of correlators instead of one, as in the case of EML and NC methods, spaced d and 2d as given in Eqn. (17). The code multipath performance mainly depends on the shape of the discriminator function SC method performs better in multipath conditions than EML and NC methods. The SC method can be used in low-complexity, low-cost GPS receivers in low-density multipath conditions.

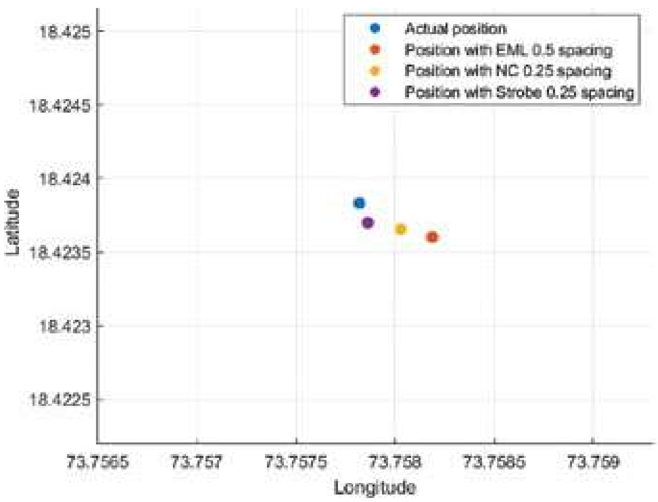
6. CONCLUSIONS

Many applications are being developed that use GPS position information. Some of these applications require high-precision location data at a higher cost. In some applications, it is cost-effective; nevertheless, lowering the receiver cost and reaching acceptable accuracy levels under specific conditions is difficult.

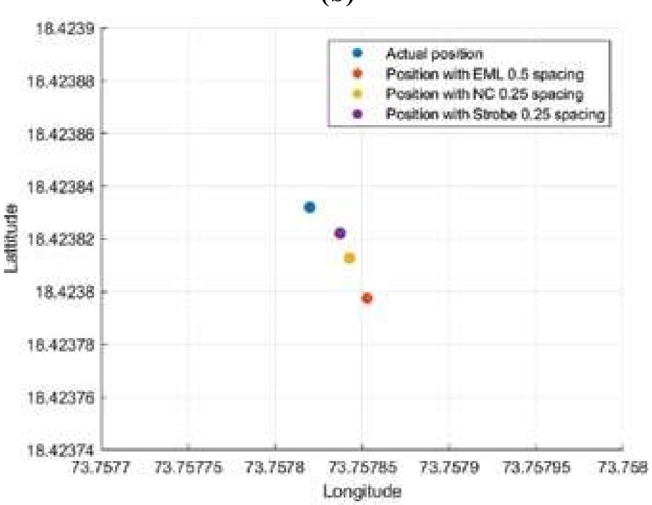
In this paper, the effect of gradually reducing the number of satellite signals with low sampling frequency data on final position output is investigated with the goal of reducing the complexity and expense of the GPS receiver. The results are compared to the actual position information, and it was observed that the reduced satellite tracking channels with suitable DOP values do not much degrade the accuracy of the position output. In this paper, the experimentation was conducted by using the GPS signals generated by a Keysight GNSS signal generator, SDR board and software-based GPS receiver. The sampling rates considered for the study are 40, 20, 10 and 5 MHz. The number of satellites is reduced from 12 to 6, then to 4 based on low DOP values; the radial error contributed to the output position relative to the actual position is 2.1 meters for a six-satellite combination and 2.7 metres for a four-satellite combination. The reduced number of satellite (four) combination with 5 MHz sampling rate signals is taken into consideration in the simulator's generation of three distinct multipath scenarios, used with three multipath mitigation methods. The error in the output position of EML, NC, and SC methods is reduced in decreasing order. Among the generated multipath scenarios, the NC method reduced



(a)



(b)



(c)

Figure 8. Comparison of receiver output positions in different MP scenarios, (a) Comparison of receiver performance in MP1 scenario, (b) Comparison of receiver performance in MP2 scenario, and (c) Comparison of receiver performance in MP3 scenario.

the error maximum to 37.8 per cent, and the SC method is 76.4 per cent compared to the standard EML method. The results show that the SC method performs better in all three multipath scenarios compared to EML and NC methods. A GPS receiver's overall computational requirement and cost can be reduced by considering low sampling frequency and fewer tracking channels. In multipath error situations, the strobe correlator method is more efficient in cost-effective receivers than estimation-based methods.

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