GPS L1 Band Civilian Simulator

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Abstract:- This paper presents the design and development of the GPS L1 Band Civilian Simulator, developed at Space Applications Centre (ISRO) for the realization of GPS Receivers and for the proliferation of GPS based applications. This paper describes the need of a GPS Simulator along with its major capabilities and supported features. The simulator generates the actual RF signals in the L1 Band for any receiver location and time. This paper also presents the signal structure of GPS L1 Band Civilian Signal. The GNSS Navigation Simulators in general and GPS Simulator in particular with RF signal generation capability is a highly expensive product, which may not be economically viable for small industries and academic institutions. The development of this GPS Simulator is a classic exhibition of how simulation and modelling can help realize systems, which can solve real world problems and create scenarios, which ultimately leads to the success of critical missions in which a GPS receiver is used. Different models have been extensively used in the realization of this simulator, starting from the modelling of the satellite motion, satellite clock degradation, and effects of Ionosphere and troposphere on transmitted signals along with high dynamic receiver motion under different scenarios. The development of this GPS Simulator will help various Indian Academic Institutions and Industries to start their independent GPS Receiver development activity, aid in numerous GPS based application development, testing and also assist researchers to work in the Satellite based Navigation Technology.

Key-Words: - Satellite, Navigation, GPS, Simulator, Modulation, Elevation, Ionosphere, Receiver
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1. Introduction

The Global Positioning System (GPS) remains the most predominant satellite based navigation system, the use of which is so ubiquitous and pervasive that its limit is restricted to the evolutionary thinking of mankind. Being the foremost satellite based navigation system, with a global coverage, there seems to be no degradation in its popularity even with the advent of GNSS from other countries like Galileo [21], Glonass [22], Beidou [23], [24] and other regional constellations like NavIC [2], [4], [5] of India and QZSS of Japan.

With the increasing use of GPS, the need for the development of GPS Receivers is increasing and companies are still coming up with interest in GPS Receiver development. Along with the design and development of GPS Receivers, there is an increasing challenge in the qualification of GPS Receivers, and to ascertain the performance of the receivers in mission critical applications and even scenarios where GPS Receiver usage is involved in safety of life. The use of GPS in automatic driving has opened a new horizon and challenge in maintaining the receiver performance and response to the signal integrity under various unforeseen scenarios. The use of GPS in aviation has already been well established. All these applications of GPS especially for use in high speed trains, aviation, automobiles necessitates the development of new innovative test cases to ascertain the realistic situation [14].

For the design, development, testing and qualification of GPS receivers under various application scenarios, the need of a GPS Simulator becomes inevitable. Navigation Simulators in general and GPS Simulators in particular are systems, which mimic the GPS constellation and generate the same RF signals as will be received from a live GPS constellation. Starting from the conceptualization to the actual deployment in a live scenario, the GPS Simulators are used to nurture the Receiver development process, fine-tune the various internal algorithms by providing the receivers with the stimulus it is supposed to receive in reality. As satellite based navigation technology progresses with new applications constantly coming up in the market, the need of GPS Simulators will go on increasing to help realize different types of GPS Receivers needed to fulfill various applications dependent on satellite based positioning techniques [14]. With the rising demand for Navigation Simulators, the market size of Simulators is expected to be 430 million USD by 2030 as per market survey [30].

This paper discusses the design and development of GPS Simulator, which has been realized at Space Applications Centre, Ahmedabad a branch of the Indian Space Research Organization (ISRO). The remainder of the paper is organized as follows. Section 2 gives a brief overview of the GPS Constellation and the system. Section 3 describes the GPS Signal Structure. In Section 4 the need of GPS Simulator is explained in detail. Section 5 describes the GPS Simulator specification, architecture and the features supported. Section 6 discusses all the test cases and validation of the simulator performance. Section 7 concludes the paper.

2 GPS Overview

The Global Positioning System (GPS) one of the greatest gift to mankind by the United States, which has been operational from 1993 with a huge number of satellites being launched in phases called blocks, each being an evolution of its predecessor. Starting from Block I the present GPS satellites belong to IIR-M, IIF, IIIA and future IIIF to be launched. With seven satellites of Block IIR, seven of Block IIR-M, twelve of Block II F and six from BLOCK IIIA, thirty-two satellites are operational in GPS constellation at present.

The satellites are organized into six equally spaced orbital planes, with each plane having slot for 4 satellites. The 6 planes are having an inclination of 55 degrees and separated by a 60 degree right ascension of the ascending node [19]. This 24 satellite constellation is guaranteed, though the number of operating satellites are more than 24 to ensure better performance. In June 2011, the 3 slots have been expanded to increase the number of satellites to 27.

The specialty of BLOCK IIR-M satellites are the addition of 2nd civil signal on L2 (L2C) [28] along with the new military M Code signal [26], which was an evolution of the earlier P(Y) code signals [27]. BLOCK IIF satellites started the third civil signals in L5 frequency specially for aviation use [28]. The latest GPS III/IIIF satellites has introduced the fourth civilian signal in the L1 Band (L1C) [10], [11], [12] as part of the GPS modernization [28]. The life span of the satellites have increased from 7.5 to 15 years for the latest GPS III-F satellites [29].

3 GPS Signal Structure

The L1 Band GPS Signal uses a family of codes called Gold Codes, which is a Pseudorandom Noise (PRN) Code repeating itself every 1ms. The code is generated using a Linear Feedback Shift Register, having a length of 1023 bits transmitted at a chipping rate of 1.023 Mcps. It basically involves the modulo 2 addition of two subsequences G1 and G2, where the G2 sequence being delayed by pre negotiated number of chips to generate different sets of C/A codes [17].

The Navigation Data of the GPS L1 signal is organized as 5 subframes, each of duration 6 secs. Each subframe is further subdivided into 10 words. The collection of 5 subframes is termed as a page. The contents of the subframe changes with the page number. Each page of GPS Navigation Data is 1500 bits long and takes 30 secs to transmit as the Nav Data is transmitted at 50 bps. Each subframe is 300 bits long and takes 6 secs to be transmitted. Each subframe is further subdivided into 10 words of 30 bits each. Each subframe starts with a Telemetry Word followed by a Handover word (HOW).

All the information about the GPS constellation is covered in 25 pages. The general structure of the first three subframes remains fixed across all the pages. The structure of the remaining two subframes 4 and 5 varies with the page numbers. The contents of the subframes used in the GPS Navigation Data are described in the following sub-sections.

3.1. TLM Word

Each subframe carries the telemetry word, which has a fixed pattern to signify the start of a subframe. The value of the fixed pattern is 0x8b, which acts as the start of the frame delimiter of the subframe, after which there are 16 reserved bits, followed by the 6 bits of parity. Each word ends with 6 parity bits and effectively contains 24 information bits. The TLM is used by the receiver to ascertain the start of a subframe and is used to ensure the receiver is locked to the actual bit sequence and to avoid the possibility of a false lock.

3.2. Handover Word

Every subframe after the TLM word contains the Handover Word (HOW). It is used to convey the satellite time to the receiver. The 17 bits of HOW often referred to as the Z-count contains the start time of the next subframe, communicated in terms of the time of week count (TOWC). The GPS TOWC gets initialized to zero at the Saturday & Sunday Midnight crossing. The value of HOW gets incremented every subframe which is of 6 secs duration. Hence, the value of HOW increments from 0 to 131071 corresponding to 604800 seconds in a week.

In this context, it needs to be emphasized that bit 18 of the HOW carries the ALERT flag, which when set to 1 indicates that the SV (Satellite Vehicle) URA (User Range Accuracy) is even degraded than what is being transmitted in Subframe1, and the use of the particular SV for position calculation is at the discretion of the receiver [20].

HOW word in bit 19 carries the (A-S) flag called the Anti-Spoofing flag. When the bit becomes high it indicates that anti spoofing mode is enabled in that particular GPS satellite and the Y code is transmitted in place of P Code [27]. The HOW word in bits 20, 21 and 22 also contains the subframe ID for the transmitting subframe for which it is part of, and varies from 1 to 5 depending on the subframe transmitted.

The following 2 bits of HOW, bit 23 and 24 are calculated by solving the parity calculation equations, with zeros in bit 29 and 30, the details of which can be found in the parity calculation algorithm [20]. In HOW, the last 2 parity bits are always 0. If p_i denotes the six parity bits of any word, with i ranging from 0 to 5, then $p_4 = 0$, $p_5 = 0$.

If d_i with i ranging from 0 to 23 denote the source bits of the HOW word, the data bit 23 and 24 of the HOW word d_{22} and d_{23} are calculated as in equation (1) and (2).

$$d_{23} = last\_D_{30} \wedge d_0 \wedge d_2 \wedge d_4 \wedge d_5 \wedge d_6 \wedge d_8 \wedge d_9 \wedge d_{13} \wedge d_{14} \wedge d_{15} \wedge d_{16} \wedge d_{17} \wedge d_{20} \wedge d_{21} \wedge p_4 \quad (1)$$

$$d_{22} = last\_D_{29} \wedge d_2 \wedge d_4 \wedge d_5 \wedge d_7 \wedge d_8 \wedge d_9 \wedge d_{10} \wedge d_{12} \wedge d_{14} \wedge d_{18} \wedge d_{21} \wedge p_5 \wedge d_{23} \quad (2)$$

where, $last\_D_{30}$ and $last\_D_{29}$ are the data bits for the previous word of the subframe.

3.3 Subframe 1

The subframe1 starts with the Telemetry word and the HOW which is same for all the subframes. The main information conveyed in Subframe1 of GPS L1 C/A code is the week number. GPS satellites have a unique way of conveying the satellite time to the receivers. The GPS week started from 6 January 1980 at 00:00:00 hours. It starts with the value of zero and gets incremented every week till 1023, after which it is again reset to 0. This event, which happens after 1024 weeks or 19.69 years approximately is called a “week rollover”. The value of 1023 comes as the week number, which is represented in 10 bits.

When the receiver gets the week number it can actually calculate the absolute week starting from 6th Jan, 1980 after taking care of the rollover events. Then the Z-count, which is obtained from the HOW as explained earlier for every subframe is multiplied by six to get the time in terms of TOWC. Thereafter, the receiver counts the number of navigation bits passed each of 20 ms duration and the number of chips within the code, with each chip of 977.517 ns duration to calculate the absolute time at which the signal is transmitted from the satellite [17].

The subframe 1 carries information which are all related to the satellite time, which includes the satellite clock bias (af_0), the rate of degradation of the satellite clock (af_1) or the first order variation of the satellite clock and the second order degradation of the satellite clock (af_2) are transmitted. The other parameters of Subframe 1 are the t_{oc} or the time of clock, which signifies the time in terms of TOWC in which the above mentioned clock parameters (af_0, af_1 and af_2) are calculated by the ground segment and uploaded to the satellite. The other information sent in subframe1 is the T_{gd} or the total group delay [20].

The first thing done by the receiver while doing the position determination is the time correction. After a successful acquisition, tracking, demodulation of the navigation data bits, the time is corrected [19] using the following equation.

$$t = af_0 + af_1 * (t - t_{oc}) + af_2 * (t - t_{oc})^2 + T_r \quad (3)$$

where, T_r is the relativistic correction [19].

The other information in Subframe1 are the User Range Accuracy (URA) index of 4 bits, a value which indicates to the receiver the amount of confidence in the transmitted satellite data. In case of degradation of the satellite clock or accuracy of the parameters transmitted, the URA index is increased so that the receiver can take the decision of including that satellite in position calculation. In addition to this, the subframe1 carries the Satellite Health parameters in 6 bits.

3.4. Subframe 2 and 3

Subframe 2 and 3 contain the ephemeris parameters of the transmitting satellite. The ephemeris parameters are needed by the receiver to calculate the exact position of the satellite in the ECEF (Earth Centered Earth Fixed) reference frame [16] at every point of time. The main orbital parameters include the eccentricity of the orbit, semi major axis, the inclination of the orbit with respect to the equatorial plane. The longitude of the ascending node, which signifies the longitude in the equatorial plane, which the satellite orbit intersects as the satellite moves from south to north [19] is also transmitted along with the argument of perigee, which represents the orientation of the orbital plane in space. The mean anomaly depicts an angle which is used to calculate the true anomaly or an angle with respect to the perigee point where the satellite is at any point of time is also part of Subframe 2.

In addition to this, other parameters include the t_{oe} or the time in terms of TOWC in which the ephemeris parameters are calculated. Along with these, there are six perturbation parameters signifying the perturbations the satellite orbit undergoes. Apart from this information, the rate of the right ascension of ascending node and the rate of change of orbital inclination is also transmitted in these two subframes. The navigation message or the parameters in the subframe changes every two hours and is signified by the issue of data ephemeris (IODE) and Issue of Data Clock (IODC) parameters.

Almanac represents the orbital and clock parameters of a satellite with reduced precision. It consists of all the parameters generally carried as part of the ephemeris parameters in Subframe 2 and 3 and clock parameters in Subframe 1, but with a reduced precision so as to accommodate more number of parameters in the subframes. The perturbation parameters are generally not part of Almanac.

3.5. Subframe 4

The contents of Subframe 4 and 5 changes with each page. The Almanac of all the satellites in the constellation are transmitted by each satellite. Subframe 4 contains the almanac parameters for Satellite number 25 to 32. Along with this, the parameters for ionospheric correction (8 coefficients) using the Klobuchar Model [15] are also transmitted in Page 18 of Subframe 4.

The GPS constellation also serves as a universal source of time used widely for time synchronization applications. As the GPS signals are available all the time globally, these signals can be used to derive time and are essential for geographically distributed terminals or systems like MF-TDMA (Multi Frequency Time Division Multiple Access) based VSAT terminals and other applications in general which require time synchronization.

The globally accepted and widely used time standard is the UTC (Universal Time Coordinated), which is adjusted with the introduction of leap seconds to keep pace with the slowing down of earth rotation with time as and when needed. As the GPS system time does not use any concept of leap seconds, the GPS time is ahead of UTC. Presently, the GPS time is ahead of UTC by 18 seconds. This information is conveyed to the receiver in page 18 of Subframe 4.

3.6 Subframe 5

Subframe 5 contains the almanac parameters for satellite 1 to 24 in each page from page 1 to page 24. In page 25, the Subfarme 5 contains the time of almanac, week number and the satellite health parameters in 6 bits. The MSB of the 6 bits is a summary of the satellite health with a zero indicating all OK and non-zero values indicates issues in the satellite health.

In this context, it needs to be understood, the need for a satellite to transmit the almanac parameters for all other satellites in the GPS constellation. Once one satellite channel is locked by the receiver, the almanac parameters can be used to find the other satellites visible to the receiver. Once the visible satellites are known, the receiver acquisition engine can search for only those satellites, thereby reducing the search time instead for searching for all satellites.

Moreover, in the acquisition process of a GPS satellite, the receiver needs to know the code offset and the doppler frequency of the satellite concerned so that the appropriate frequency bin can be directly searched. From the almanac parameters, the position of all the satellites along with the approximate Doppler frequency of the satellite can be calculated which aids the acquisition process [18].

With a combination of 25 pages, which takes 12.5 minutes for the satellite to transmit, the receiver is made aware of the complete prevailing state of the GPS constellation by the navigation data transmitted by the GPS satellites. Every subframe of GPS has 10 words of 30 bits each. The last 6 bits of each word is the parity bits. The 24 bits of each prevailing word and the last 29th and 30th bit of the previous word are used to calculate the 6 bit parity the details of which are available in [20].

4 Need of GPS Simulator

The GPS Constellation is operational for years, however still for the GPS Receiver development cycle the GPS Simulator is an indispensable system. The GPS signals are already available from the open sky, but still the live sky signal is not the best choice for GPS Receiver development. The operational check of the GPS Receivers can certainly be done using the live sky signals, but the design, development and qualification of receiver algorithms need a simulator mainly because of the reasons described in the following sub-sections.

As we know, the main error sources in GPS receiver position computation are the errors due to satellite ephemeris and satellite clock performance prediction. Errors are also introduced due to inaccurate estimation of the Ionospheric & Tropospheric condition as the signal passes through these layers of the Atmosphere. The ionospheric error remains the most significant source of error as it is very difficult to predict the ionospheric Total Electron Content (TEC) density [17], especially in equatorial anomaly [6] region. The multipath phenomenon in dense urban environment also contributes to the GPS error budget along with errors arising from receiver noise [17].

The live GPS constellation signal has all the errors discussed before in a combined form. During the GPS receiver development cycle, the effects of different error sources like the satellite ephemeris errors, satellite clock errors, ionospheric errors, tropospheric errors, multipath errors on the receiver performance need to be separately addressed. If a live GPS signal is used, is becomes very difficult and non-deterministic to exactly quantify the contribution of each error source. On the contrary, using a GPS Simulator, each and every error contributing sources can be separately made active. The verification of the concerned receiver algorithms can be accomplished and necessary fine tuning generally needed during the development phase can be achieved.

The amount of error present for each error contributing source cannot be ascertained in a live GPS signal. For example, the ionospheric errors present in a live GPS signal cannot be quantified with very high accuracy. However, using a GPS Simulator, an exact amount of Ionospheric error may be introduced in the signal. There is also a possibility in the Simulator of no ionospheric errors being injected in the signal at all, which is never possible using a live GPS Signal. This criterion is true for all the error contributing sources mentioned. The capability of quantifiable error injection actually helps in the design and development of new algorithms and performance verification of existing methodologies implemented in the receiver.

Whenever, any new algorithm is designed and developed, the need for repeatedly testing the algorithm with the same stimulus becomes very important. The performance of the algorithm can be evaluated only if the test environment remains the same. With a live GPS signal, it is difficult to recreate repeatable scenarios for testing. At every instance of time, the GPS satellites in the constellation will change their position, the predicted satellite ephemeris and the satellite clock errors will be different. Along with this, the effect of ionosphere and troposphere cannot remain the same and the multipath error may also vary. The overall geometry created by the visible GPS satellites and the receiver, which in turn governs the Geometric Dilution of Precision (GDOP) [19], will differ leading to a different error value in the position computation. The signals from the GPS satellites will arrive at the receiver with different time offsets and Doppler values, which would be different in every test iteration. This becomes a major bottleneck in testing using a live signal.

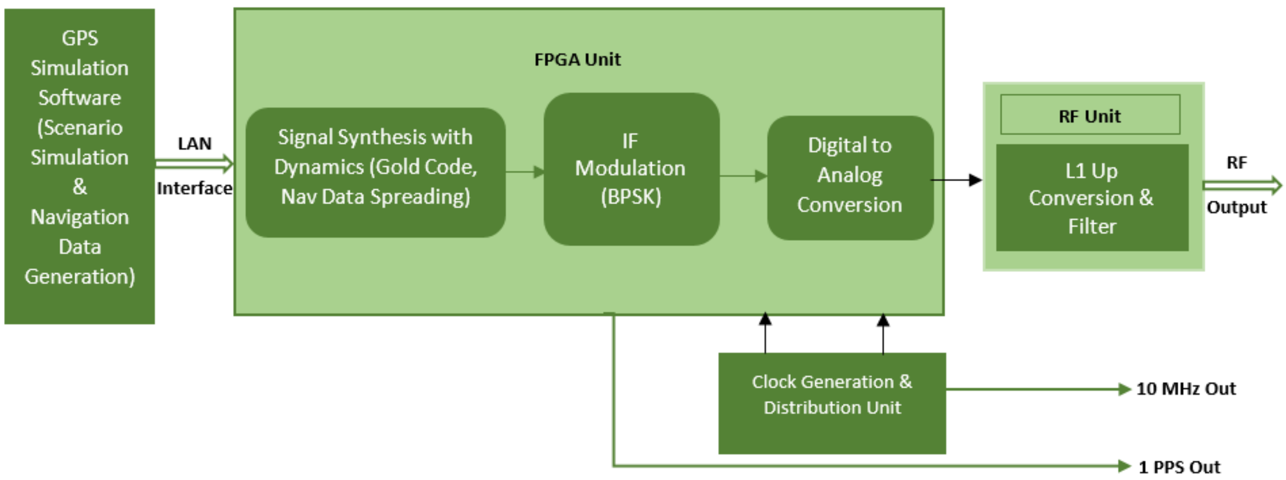

Fig. 1. GPS L1 Band Simulator Architecture

On the contrary, using GPS Simulator, the state of the constellation, the exact amount of errors from the different error sources, the geometry of the constellation, all can be repeated ensuring signals generated being similar even upto the code and carrier phase values. This helps in the design and development of various receiver algorithms and also in comparing different algorithm efficacy or comparing the performance of receiver from different make.

The most important utility of the GPS Simulator comes when the newly designed GPS Receiver needs to undergo a dynamic scenario testing. Using the live GPS signals, the receiver needs to be mounted in high speed automobiles, trains or aircrafts for high dynamics testing, which is quite inconvenient, time consuming and not economically viable especially when the receiver development is in its infancy. Using a GPS Simulator, the designed receiver can be subjected to these dynamic environments, in a highly controllable and repeatable manner, which will highly aid in the high dynamic receiver performance evaluation. The performance of receiver in high speed trains, unmanned landing of an aircraft, guidance of a satellite launch vehicle can all be ascertained in a controlled laboratory environment. The performance of the algorithms can be fine tuned after analysis of the dynamic test results. This approach is economical, reduces the development time and gives confidence in the receiver capability before the actual deployment in the field.

All these above mentioned reasons make the GPS Simulator an indispensable system in the GPS Receiver development process.

5 GPS Simulator Architecture

A 12 channel GPS L1 Band Simulator has been designed and developed at Space Application Centre (ISRO), which has the capability to simulate the 32 satellites of the GPS constellation civilian signals in the L1 frequency Band. The GPS Simulator mimics the entire GPS Constellation and generates GPS RF signal in the L1 Band as will be received by a GPS receiver from the actual GPS Constellation.

The GPS Simulator consists of a Simulation Software, FPGA Signal Generation Unit and RF Up-Conversion Unit. The scenario simulation along with the generation of the navigation messages is performed in the software. These simulation parameters are utilized by the FPGA based unit for the complete signal synthesis as per GPS ICD [19].

The realization of the GPS Simulator primarily involves the synthesis of 32 GPS satellite signals in real time. This entails implementation of the codes pertaining to the individual satellites, the navigation data and the signal modulation. The combined satellite signals for all the satellites in L1 Band is available from the RF output of the Simulator as shown in Fig 1.

GPS being a global constellation, using MEO orbiting satellites, not all satellites are visible to a receiver at any point of time. The aim of the GPS Simulator is to present the RF signals of only those satellites that are visible to the receiver. This creates a challenge in the Simulator realization, as at some given point of time, some satellites move below the horizon and new satellites come up the horizon. The signals only from the satellites above the horizon need to be incorporated in the generated RF signal from the Simulator.

The first task of the GPS Simulator is to determine the number of visible satellites from the receiver location. The GPS Simulator has 12 hardware RF channels corresponding to 12 satellites visible from any point on the earth. The set of visible satellites is dynamically controlled to accurately simulate the rising and setting of satellites. Once the simulation scenario starts, it is ascertained that a satellite is included in the visible set only when it comes above a certain elevation angle threshold. Then the RF signal generation process is configured in such a way that only signals from the visible satellites are presented to the Receiver.

There are some software based GPS IF Signal Simulation techniques available in [3][7][8][9][13], which are primarily targeted for development and evaluation of Software based GPS Receivers [18]. The Simulator design presented in this paper uses a combination of hardware and software design as shown in Fig 1. Authors have realized a NavIC Tri-Band (L1, L5, S) SPS Simulator using a similar approach for the design and development of NavIC Receivers [1]. The broad specification of the Simulator is as shown in Table I.

TABLE I
GPS SIMULATOR SPECIFICATIONS

Hardware Channels	
Number of Channels	12 channels
PRN code selectivity	Any PRN number among 1 to 32
Output Frequency	
GPS L1	1575.42 ± 20.46 MHz
Reference Clock Specification	
Reference clock source	10MHz (OCXO)
Frequency Stability – Long term	$\leq \pm 10^{-9}$
External reference input	10 MHz, 0dBm ± 3 dB
Phase noise of Reference source (10MHz)	≤-135 dBc/Hz @ 1KHz ≤-143 dBc/Hz @ 10KHz ≤-144 dBc/Hz @100KHz ≤-146 dBc/Hz @ 1000 KHz
Signal quality	
In band spurious	≤-40dBc
2nd Harmonic spurious	≤-40dBc
Spurious free dynamic range (SFDR)	≥48dBc
Carrier Suppression	≥ 30dB
Amplitude Imbalance	≤ ± 0.5 dB
Phase Imbalance	≤ ± 2 deg.
Error Vector Magnitude	< 10% RMS
RF Output power level	
RF Signal Power Level	-130dBm (Typical)
Range	±20 dB
Resolution	0.1dB

In the GPS Simulator, all the signal structures described in Section III have been implemented with the generation of Pseudo Random Codes, navigation data and the signal modulation as per the data structure and generation of the actual RF signals in the L1 Band. The inputs required to setup the GPS Simulation Scenario includes parameters like receiver position, the simulation time and enabling / disabling of different error sources. The Simulator generates the modulated RF signal as would have been received from the actual GPS Constellation at the specified receiver location and simulation time.

The receiver performance needs to be evaluated at different locations. This is important to ascertain the receiver position accuracy in different parts of the world as the Geometric Dilution of Precision (GDOP)[19] of the GPS Constellation varies with location and time. The simulation time can also be changed to any date and time in past or future to check the performance of the receiver.

As the GPS signals traverse through the ionosphere of the atmosphere, it is subjected to a phenomenon called code-carrier divergence [17], where the code is delayed and the carrier is advanced. This effect has been implemented in the GPS Simulator where the code and carrier is subjected to the effects as it happens in reality. The GPS signals are also delayed by the troposphere of the atmosphere [16]. The Simulator has the capability to simulate the tropospheric effects. In addition to this, errors occurring due to satellite ephemeris, satellite clock and satellite perturbation can be simulated in the Simulator. The Simulator has the provision to simulate fixed power levels for individual satellites along with the precise variation of power arising from the motion of the satellite and receiver, even taking into account the receiver antenna gain pattern. Moreover, the high dynamic scenarios can also be tested using the Simulator without leaving the laboratory environment.

The performance of the GPS Simulator has been tested using various test cases as described in the following section. The ultimate RF output signal of L1 Band is available at -130 dBm from the RF output port of the Simulator. The Simulator also has the provision to generate 1PPS and 10 MHz signals generally needed for receiver development and testing.

6 Test and Evaluation

Several tests have been conducted to characterize the performance of the Simulator related to signal fidelity, SFDR, and signal harmonics as shown in Table II. The GPS Simulator has also been tested with M/S Accord [25] developed GPS Receivers as shown in Fig 5 and the receiver GUI shown in Fig 6. The Receiver is provided with the input RF Signal generated by the Simulator. All the visible GPS satellite signals for the L1 Band are acquired by the M/S Accord Receiver for the L1 Band as shown in Fig 6 along with the position solution being achieved.

TABLE II
SIGNAL FIDELITY TEST RESULTS

Signal Parameters	Measured Values
In band spurious	-56dBc
2nd Harmonic spurious	-66 dBc
SFDR	55 dBc
Carrier Suppression	61dB
Amplitude Imbalance	0.2 dB
Error Vector Magnitude	6 %

The static test, where the receiver position remains fixed with time, has been conducted with all the atmospheric impairments like ionosphere and troposphere [16]. At the start of the configured simulation scenario, a total of 10 GPS satellites were visible to the receiver which includes PRN 2, 5, 6, 11, 12, 19, 20, 24, 25 and 29. The ionospheric errors in meters as imparted by the simulator for all visible satellites is shown in Fig2. Similarly, the tropospheric errors generated by the simulator for the set of visible satellites is shown in Fig3. It can be seen that the tropospheric error is maximum, when the elevation angle is low [17], as is the case for satellite number 29 in the simulated scenario. The variation of the elevation angle as calculated and logged by the Simulator is shown in Fig4. The simulator logged receiver position values were compared with the receiver obtained values and their difference calculated every second. The resultant 3D RMS error is approximately 17 cm.

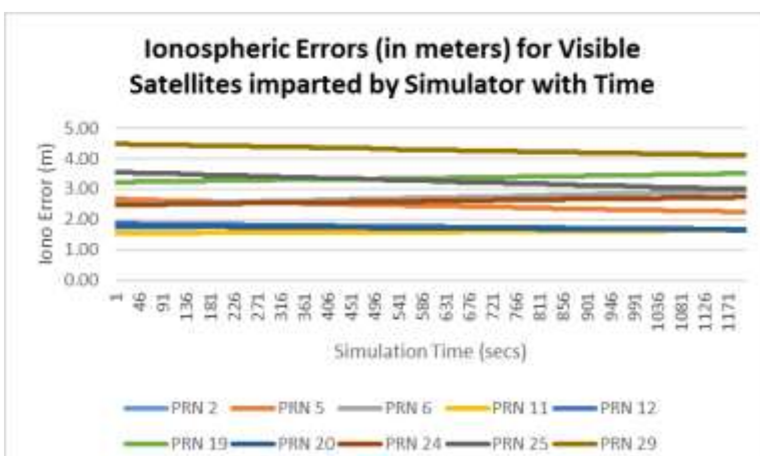

Fig. 2. Ionospheric Errors imparted by Simulator

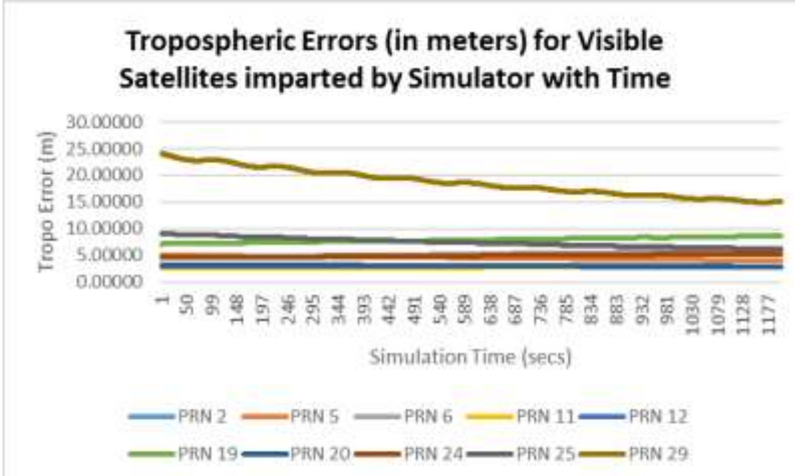

Fig. 3. Tropospheric Errors imparted by Simulator

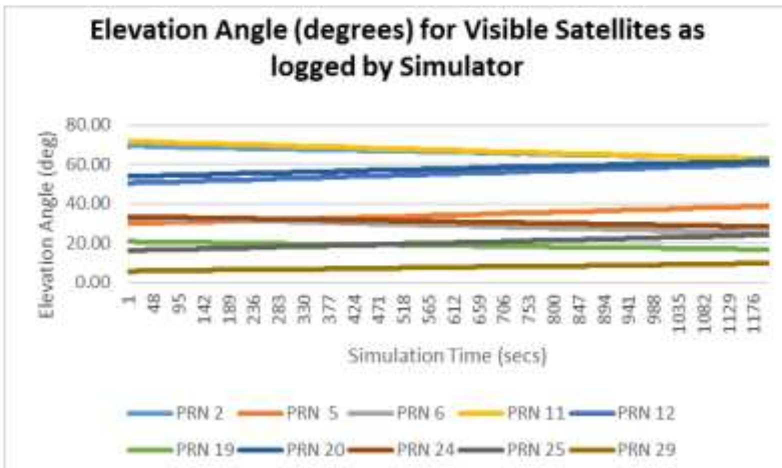

Fig. 4. Elevation Angle as logged by Simulator

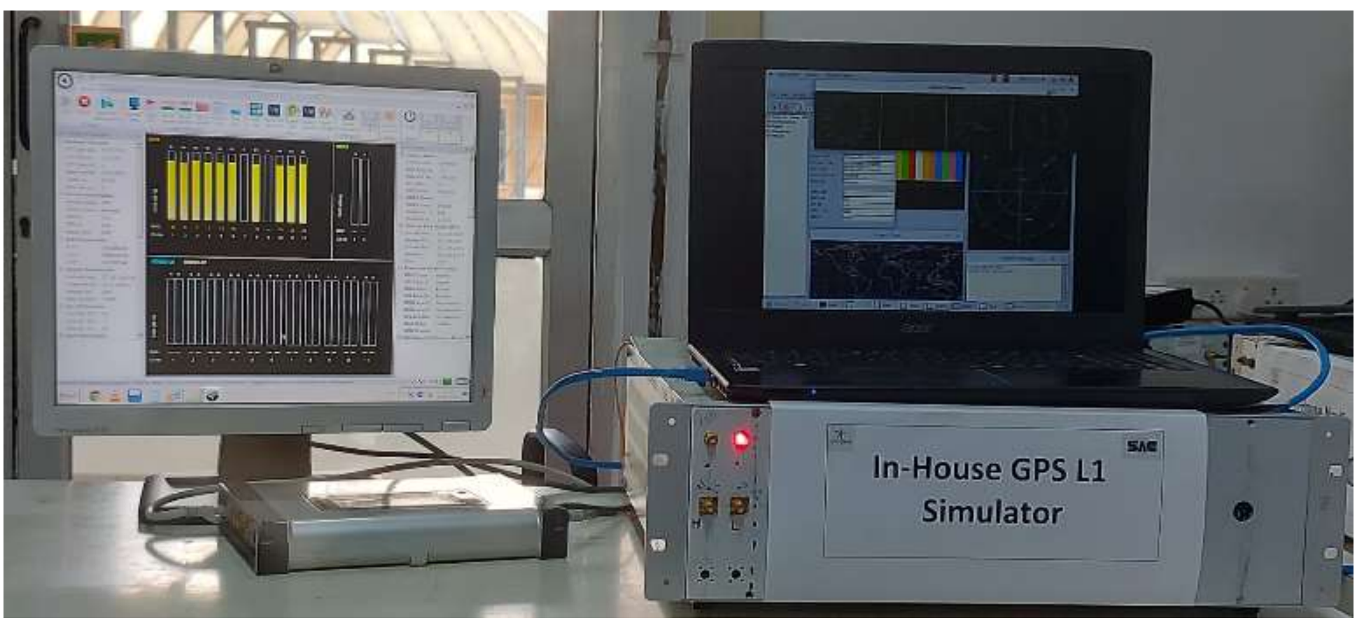

Fig. 5. GPS Simulator Test Setup

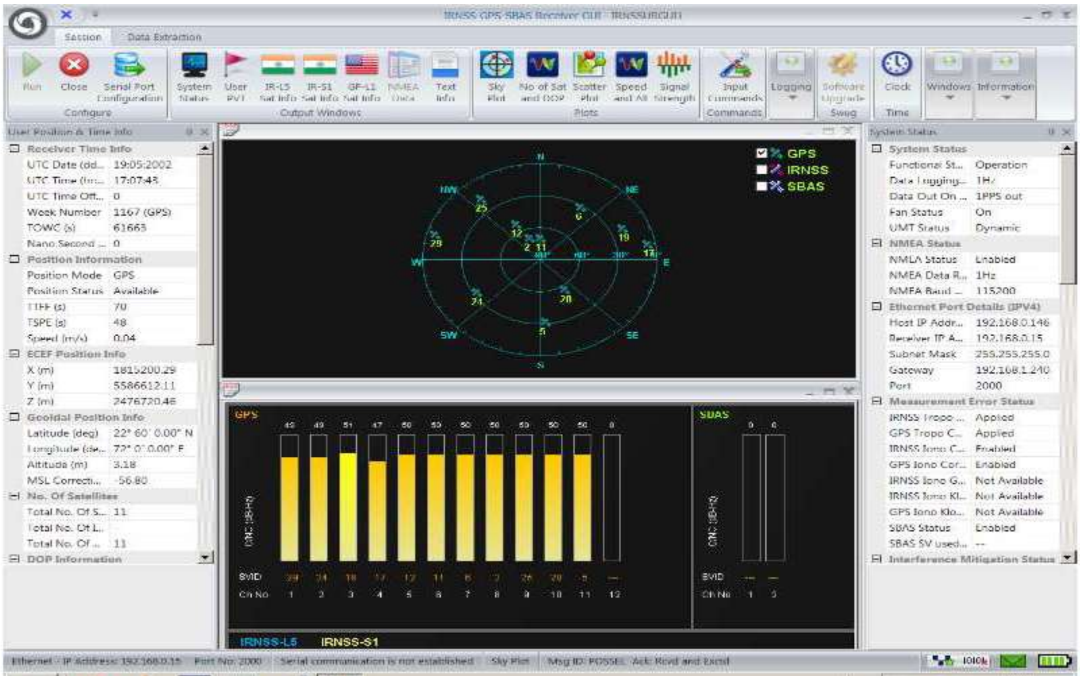

Fig. 6. GPS Simulator with M/S Accord GPS Receiver [25]

The capability of the Simulator to generate dynamic simulation scenarios is verified by creating a scenario where the Receiver moves at a constant velocity of 515 m/s (1854 km/hr) in a circular track. This is the highest velocity permissible for civilian Receivers. All the effects arising because of the high receiver dynamics have been successfully synthesized by the Simulator, like the very high Doppler, which will be experienced due to the high variation in the satellite and receiver relative velocity. The Doppler values imparted by the Simulator for the respective satellites is shown in Fig7. If the Simulator is perfectly creating the dynamic scenario in the lab environment, where actually the receiver is remaining static, but the received signal is artificially being subjected to the effects as if it is moving at a very high velocity by the simulator, the computed receiver velocity will be very high. The Receiver acquires the signal even in the presence of the very high Doppler values and the velocity obtained by the Receiver matches with the simulator imparted velocity of 515 m/s as is shown in Fig8. In Fig8, considering the dynamic scenario, the Receiver GUI shows the PRN locked, the C/No achieved, the pseudoranges of the visible satellites, azimuth & elevation which was as expected from a live GPS constellation signal. This shows the efficacy of the GPS Simulator in recreating the dynamic scenario as the receiver is transparently processing the signal as if the signals are coming from a live GPS constellation. This is the main objective of the developed GPS Simulator, to artificially generate a test environment, which is close to the reality and that has been achieved.

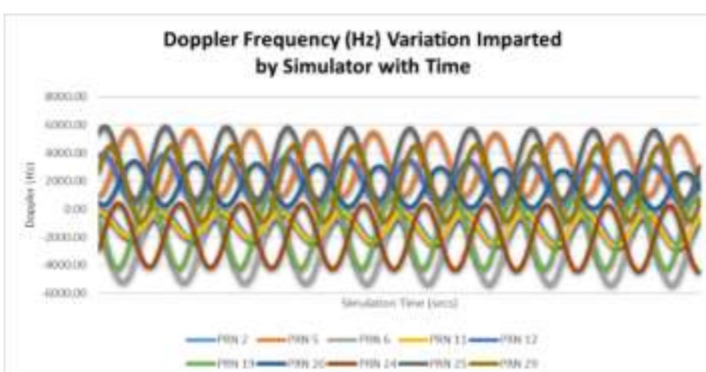

Fig. 7. Doppler frequency imparted by Simulator

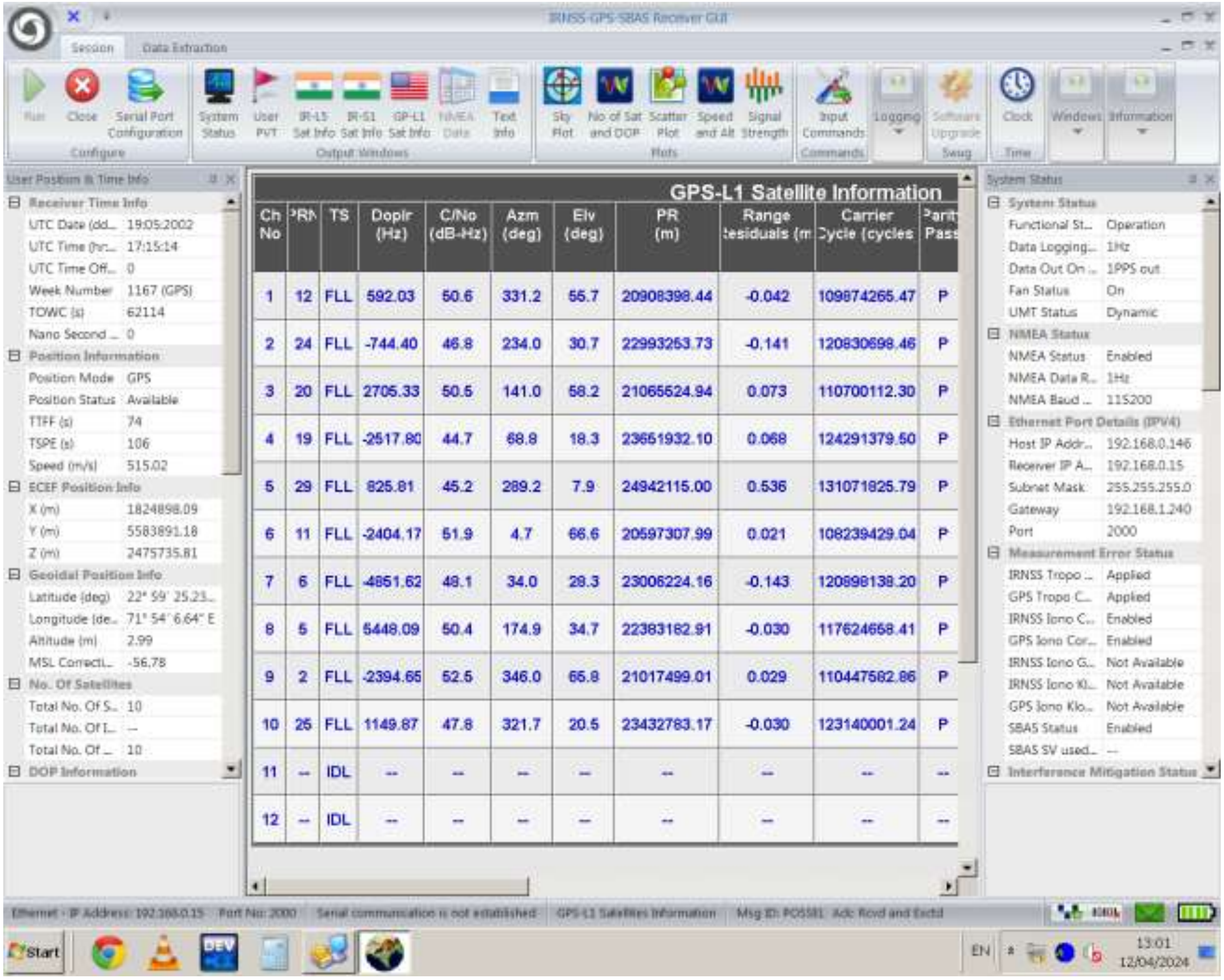

Fig. 8. GPS Receiver GUI with dynamic scenario

7 Conclusion

The design and development of the GPS Simulator has been undertaken at Space Applications Centre, ISRO, which generates the GPS constellation civilian signals in the L1 Band. The full constellation of 32 GPS satellites has been realized in the Simulator. The simulator synthesizes the propagation effects with all the error contributing sources as the signal traverses from the satellite to the receiver. The signal structure of GPS as per the ICD [19] has been realized in the simulator. As satellite based navigation proliferates, throughout the world in general and India in particular, there will be a huge demand of GPS receivers and increased industry participation. Many Indian small scale industries and academic institutions will engage in research on satellite based navigation and associated applications. Considering the importance and huge cost implication of simulators in the complete receiver development eco-system, this developed simulator will be beneficial to academic institutions and industries. This simulator will help drive the GPS receiver development from conceptualization, testing to ultimate product delivery and aid in the envisaged future utilization of GPS based applications.

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