Multi GNSS (IRNSS-L5, IRNSS-S1, and GPS-L1) Hybrid Simulator: A Reconfigurable Low-cost Solution for Research and Defence Applications

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ABSTRACT

Satellite-based positioning field of research is growing rapidly as there is an increase in demand for precise position requirements in various civil and commercial applications. There are many errors that affect the GNSS signals while propagation from satellite to receiver, which eventually induces errors in pseudo-range measurements. In order to assess the receiver characteristics for a specific error condition, the real-time signals may not be appropriate, and it is challenging to perform repeated experiments with the same error condition. The advantage of the GNSS simulator is that users can model the different scenarios for any given location on the globe, which are repeatable at any point of time. The conventional hardware simulators are expensive and have few limitations. In this paper, a reconfigurable hybrid simulator is proposed with some advantages over traditional hardware simulators, such as low cost, reconfigurability, and controllability over fundamental parameters. It can be able to record intermediate stage data, which makes it more suitable for the GNSS research field. The proposed multi-GNSS simulator considered implementing IRNSS-L5, IRNSS-S1, and GPS-L1 band signals. A general-purpose computer can perform the necessary calculations for signal generation. The hybrid simulator can be able to generate the digital I/Q data, which can be stored as I/Q data or can be connected to a general-purpose SDR (Software Defined Radio) for RF signal generation (bladeRF in this case). The I/Q data can be used with the software receiver to analyse the receiver performance concerning the specific error. The generated GNSS signals are validated with software and hardware receivers, and the obtained position is observed as expected. The applications of this work are in the fields of research, receiver performance analysis under different user-defined scenarios, and the development of new GNSS signals, as well as in the defence field, where it can be used as a GNSS spoofing system.

Keywords: SDR-based GNSS simulator; IRNSS-L5/S1 signal generator; GNSS spoofing; Pseudo-range calculation; Reconfigurable GNSS scenario generator

1. INTRODUCTION

Global Navigation Satellite System (GNSS) is expanding in various fields with a wide variety of applications[1]. As the demand for accurate positioning information is increasing, hence the technology is getting improved day by day. In GNSS research, there are numerous limitations associated with real-time signal usage.[2] Two approaches for obtaining GNSS signals for research are, using an RF front-end module to receive live GNSS signals and record them as digital data[3,4] or using a GNSS signal generator to generate a digitized baseband signal. The GNSS signals are time-varying as the satellites are constantly moving, and atmosphere conditions also may vary the signal characteristics.[5] Most of the time, it is requisite to perform a particular test several times with the same scenario conditions; in such situations, the real-time signals might not be suitable to analyse the GNSS receiver performance.[6,7] It is recommended to use simulated GNSS signals rather than live GNSS signals each time.[5,8-9] In the case of recorded GNSS signals with the RF front-end board, the quality of the signal is influenced by the antenna, noise figure, and the filter response of

the board.[8] On the other hand, software-based GNSS simulators are gaining popularity for real-time implementation of the GNSS system for investigation and improving the receiver performance in user-defined conditions.[5,10,11] In receiver performance analysis, the main advantage of the software-based receiver is that it can decouple the hardware-related nonlinear, temperature dependant components[12] and actual receiver performance.

Many institutes and researchers may not afford the commercial GNSS simulators because of their high cost.[5,7,13,14] Most hardware-based simulators allocate a dedicated processing section for each visible satellite channel. These channels operate in parallel processing mode.[15] For a large number of channels, the cost of the simulator increases considerably.[5,13] The conventional hardware simulators have some limitations, which are not reconfigurable, controllability on fundamental parameters is limited, intermediate stage data is not accessible, and they are high cost. In this paper, IRNSS and GPS signals are generated using standard documents[16-17] as references, beginning with basic parameter calculations at the subframe level and advancing to RF signal generation. The proposed GNSS simulator is hybrid in the sense that it can generate digital data files in I/Q format as well as the RF signal to perform better testing capabilities. For a user-defined

scenario, the signal is generated using the required scenario parameters, which can be fed into the simulator. It has provision to generate baseband I/Q signal which can be stored and used for repeatable experiments. The same signal can be used with RF generating board to generate GNSS RF signals which can be run several times into a specific GNSS receiver to provide a statistical estimate of the receiver performance[8]. The proposed GNSS simulator attempts to reduce the overall computational cost; it requires only a general-purpose computer that can calculate the parameters and generate a digital baseband signal. To generate RF signals, a general-purpose single RF generator board is required for each GNSS band, with its specifications matching the requirements making it cost-effective compared to the hardware GNSS simulators. Due to the controllability over fundamental single parameters, the generated signals can incorporate the majority of the errors found in actual signals, such as clock, atmospheric, multipath, and interference errors.[10,18]

The software-based simulators have complete access to all the parameters[9-10,13]. They have the advantage of logging the data at any intermediate stage, which helps in comparing the received parameters with the transmitted parameters. The main advantage is that all the errors included in the generated signals are exactly known values enabling the user to turn on or off a specific error. Hence the receiver testing can be more precise, and specific error component contribution to the receiver performance can be assessed[2,7,19]. The reconfigurable simulator has the flexibility to simulate not only the existing GNSS constellations but also new upcoming constellations with user-defined modulation, multiplexing schemes and different Pseudorandom Noise (PRN) codes. They have access to all the individual parameters, which is not the case when using proprietary simulators. It allows testing new signal generation and validation to become easier[7,20-21].

2. GNSS SIGNAL STRUCTURE

In this work, GPS and IRNSS constellations signal generations are considered. Both the GNSS constellations follow similar signal generation architecture, as shown in block diagram Fig.1. These GNSS signals consist of three fundamental components - navigation signal, coarse acquisition (C/A) code, and carrier signal. Navigation signals contain information related to satellite positions in the form of Keplerian orbital parameters and information related to clock, error corrections, and other status flags[10]. C/A code sequence is unique for each satellite representing the identity of an individual satellite. The carrier signal is a sinusoid with a fixed center frequency as per the standard band of operation[22]. A simplified model is
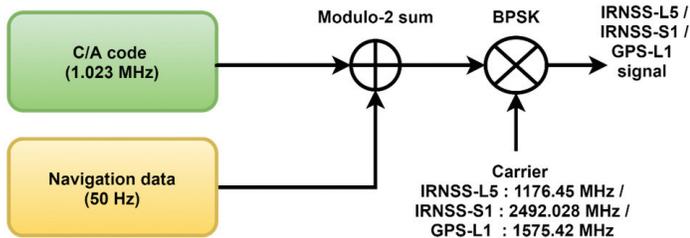
Figure 1. A simplified model for GNSS signal generation configuration.

shown in Fig. 1. The C/A code chipping rate is 1.023 MHz, and the navigation signal data rate is 50Hz. The C/A code is XORed with the navigation data, i.e., same as the modulo-2 sum operation. The resultant sequence is BPSK modulated with a sinusoidal carrier signal. The carrier signal frequencies for IRNSS-L5, IRNSS-S1, and GPS-L1 are 1176.45 MHz, 2492.028 MHz, and 1575.42 MHz, respectively.

The signal transmitted from the ith satellite at time t is defined by[21, 23]

$$Tx_i(t) = A_i D_i(t) C_i(t) \cos(\omega_{Si} t) \tag{1}$$

where A_i is the signal amplitude, $D_i(t)$ is navigation data, $C_i(t)$ is coarse/acquisition code, and ω_{Si} is the frequency of the carrier for the ith satellite.

In GNSS simulators, generated signals are delayed and corrupted by propagation errors received by the receiver front-end[12,15].

$$Txu_i(t) = A_i D_i(t - \tau_i) C_i(t - \tau_i) \cos((\omega_{Si} + 2\pi f_{i\_dop})t + \phi_i(t)) + n(t) + Tx_{i_{MP}}(t) \tag{2}$$

where, τ_i is the propagation delay, f_{i_dop} is Doppler frequency, $\phi_i(t)$ carrier phase, $n(t)$ is the noise, $Tx_{i_{MP}}(t)$ is multipath reflected signals for i^{th} satellite[24].

3. GNSS SIGNAL GENERATION

As part of the multi-GNSS simulator design, three operational bands of GNSS signals, namely the IRNSS-L5 band, the IRNSS-S1 band, and the GPS L1 Standard Positioning Service (SPS), are taken into consideration.

3.1. Indian Regional Navigation Satellite System (IRNSS)

IRNSS is the independent and ingeniously developed regional satellite navigation system; the primary purpose is to avoid dependency on a foreign satellite system in military operations[25]. The primary service area coverage of the Indian region along with 1500 km surrounding the country[4], as represented in Fig. 2.
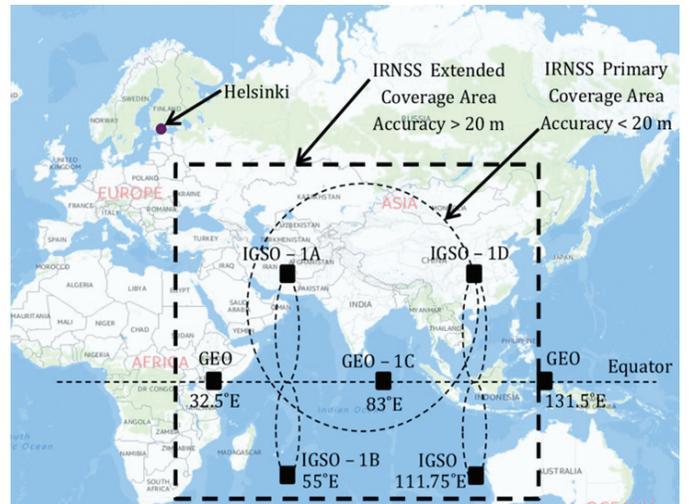
Figure 2. IRNSS coverage area representation[26]

The IRNSS constellation consists of seven geo orbital satellites; among these, three are geostationary orbit (GEO) satellites placed in the orbit at 32.5^0 E, 83^0 E and 131^0 E longitude and four are geosynchronous orbit (GSO) satellites - two satellites cross the equator at 55^0 E and the other two at 111.75^0 E[25]. IRNSS operates in two different frequency bands - L5 carrier frequency at 1176.45 MHz (24 MHz bandwidth) and S1 carrier frequency at 2492.028 MHz (16.5 MHz bandwidth)[16,28].

3.1.1 IRNSS L5 Signal Generation

The proposed GNSS simulator signal generation design of the IRNSS L5 band is explained in Algorithm 1.

3.1.2 1GNSS Signal Generation Algorithm

Algorithm 1. GNSS signal generation for IRNSS L5 band

Input: Latitude, longitude, altitude and time for the required scenario, sampling rate, RINEX/almanac file
Output: I/Q data file and RF signal

Step 1: Convert input location information and satellite positions into X, Y, Z coordinates of the ECEF reference frame.
Step 2: Calculate Elevation and azimuth angles to decide the number of satellites N in view, i.e., valid PRN list
    For i <= N do
Step 3: Generate a C/A code for the corresponding PRN number.
Step 4: Extract satellite position parameters and other components from the RINEX/Almanac file, and convert the required parameters as per the standards.

Step 5: Calculate the timing parameters for the scenario time.
Step 6: Design all the subframes by placing parameters in their designated positions according to the standards given in the ICD document with all required conversions and calculations of the parameters.

Step 7: Calculate the distance between the corresponding PRN satellite to the given user position, and convert it into the code phase according to the sampling rate.
Step 8: Calculate Doppler frequency values.
Step 9: Incorporate code and carrier phase, and perform XOR operation between C/A code sequence and navigation data according to the sampling rate.
Step 10: Modulate the resultant sequence with BPSK(1) modulation.

    End of For loop
Step 11. Add any optional user-defined errors and combine all the N satellite signals.
Output1: Save the sine and cosine component signal as I/Q data in binary file format in the local drive.
Output2: To Generate an RF signal, a general-purpose RF generating board like SDR (bladeRF) can be used with provided carrier frequency, sampling rate, and gain.

Steps involved in GNSS signal generation are outlined in Algorithm 1, which requires some scenario-specific input parameters like latitude, longitude, altitude, and time, along with the Receiver INdependent EXchange (RINEX)/almanac data file. The RINEX data of IRNSS and GPS used as input is recorded by Accord software and systems multi GNSS receiver[27]. In Algorithm. 1, step 1, scenario position is converted into X_U, Y_U, and Z_U coordinates in the Earth Centred Earth Fixed (ECEF) reference frame. Satellite positions are calculated in X_S, Y_S, and Z_S coordinates in the ECEF reference frame from the ephemeris parameters in the RINEX/almanac file, which are in the form of Keplerian orbital parameters. In Algorithm 1, step 2, elevation and azimuth angles are calculated for each satellite for the given scenario position. Based on the position of the satellite, the valid PRNs (N number of satellites) are chosen for the signal generation.

As discussed in the previous section, there are three components for signal generation. In the process of generating GNSS signals, first, start with C/A code generation for each satellite.
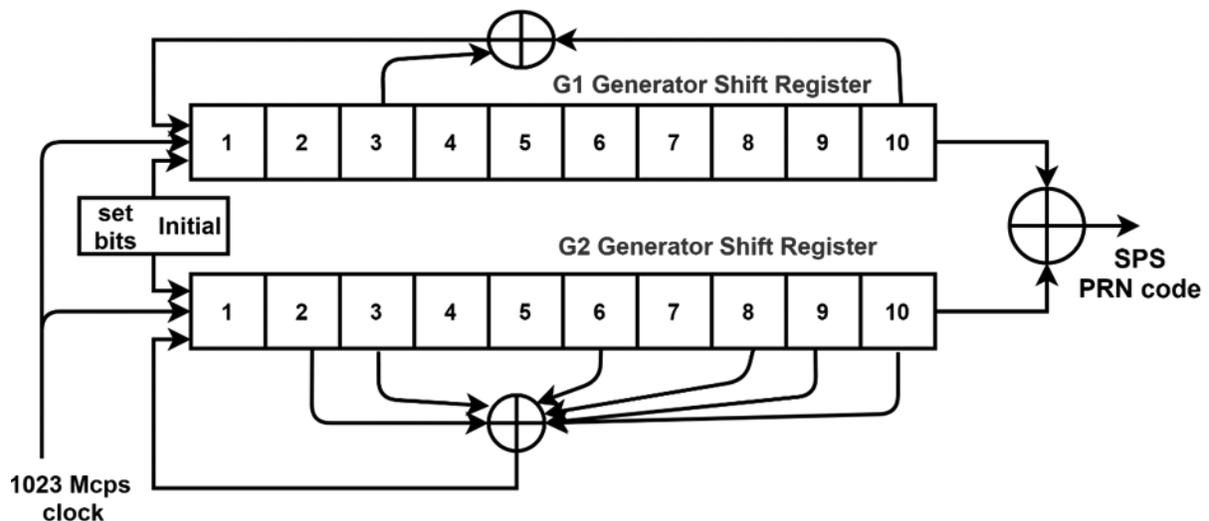

Figure 3. SPS code generator.

3.1.3 C/A Code Generation

As depicted in Algorithm. 1, step 3 for all the valid PRN satellites, C/A code is generated. In the SPS signals, the C/A code is generated by using two polynomials as given in the Interface Control Document (ICD) standard document[16] shown in Fig. 3. The length of the code is 1023 chips at a chipping rate of 1.023 Mcps. Polynomials for obtaining shift registers $G1$ and $G2$ are in Eqn. (3).

$$G1 = X^{10} + X^3 + 1$$
$$G2 = X^{10} + X^9 + X^8 + X^6 + X^3 + X^2 + 1 \qquad (3)$$

The initial bits for the $G1$ shift register are all 1's, and for the $G2$ shift register are given in the ICD document[16](refer to Table. 1). As per the IRNSS constellation, seven satellite C/A codes are generated.

values obtained from different satellites. Based on these values and navigation parameters, the receiver calculates its position. A small error in pseudo-range may result in a different location on the receiver.

3.1.6 Doppler Frequency Calculations

Doppler frequency is naturally created over the center frequency of an actual band's operating frequency range due to the speed at which satellites move in relation to the user. From the receiver's point of view, Doppler frequency measurement determines whether the user is stationary or moving. Therefore, precise calculation of Doppler frequency is essential in simulator design and its update rate. In Algorithm. 1, step 8, Doppler frequency values can be calculated[24] by the Eqn. (4). The satellite velocity is computed from the ephemeris information for the respective satellite[22]. The Doppler frequency values are computed using the satellite's position and velocity

Table 1. IRNSS L5 initial G2 bit sequence for SPS signals

PRN ID	1	2	3	4	5	6	7
Initial bits $G2$	1110100111	0000100110	1000110100	0101110010	1110110000	0001101011	0000010100

3.1.4 Navigation Data

Navigation data is generated using the RINEX/almanac file, which contains satellite parameters, as shown in Algorithm. 1, step 4. All the parameters are extracted from RINEX/almanac file; some parameters are required to be converted according to the generating scenario information. These parameters are further modified according to the standard subframe structure format given in the ICD[16] document. The parameters required to generate the subframe are perfectly placed in the designated locations in the subframe structure. In Algorithm. 1, step 5, the timing parameters according to the subframe standards are calculated based on the scenario time input. The same timing parameters are expected to be recovered at the receiver.

IRNSS navigation data master frame is of length 2400 symbols are generated. This master frame is split into four subframes consisting of 600 symbols each as shown in the Fig. 4.
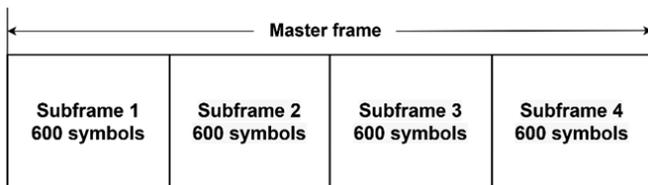

Figure 4. IRNSS master frame structure.

IRNSS subframe parameters are given in Appendix-I; the converted form of these parameters are placed in their designated positions according to the standard ICD[16] document, as given in Algorithm. 1, step 6.

3.1.5 Pseudo-range Calculation

The satellite positions and input scenario positions are converted into cartesian coordinates. The pseudo-ranges are calculated between the input scenario position to each valid satellite in the view, explained in Algorithm 1, step 7. The most important measurement in a GNSS receiver is the pseudo-range

with respect to the position and velocity of the generating scenario information[23]. The computed Doppler values are incorporated in the satellite signal Eqn. (2) based on the sampling frequency[14]. The signal parameters calculations are performed at a rate of 1 Hz; for the dynamic scenario, the relative velocity values and Doppler frequencies are calculated for every second and used in the signal generation.

$$f_{i\_dop} = \frac{v_i}{c} f_{cent} = \frac{R'_i}{c} f_{cent} \qquad (4)$$

f_{i_dop} Doppler frequency, v_i is velocity, c is the speed of light, R'_i is the relative velocity between satellite and receiver, and f_{cent} is transmitting frequency for i^{th} satellite.

In conventional hardware GNSS simulators, the sampling rate is fixed by the designer based on the hardware board specifications[13]. In the case of a software simulator, the user can specify the sampling rate during signal generation. In Algorithm 1, step 9, generated C/A code and navigation data bitstream are sampled at the given sampling rate, and an XOR operation is performed between two bitstreams. In the resultant bitstream, code phases are assigned, which are calculated from obtained pseudo-ranges. In Algorithm 1, step 10, BPSK(1) modulation is implemented to the resultant signal, as per the standard modulation scheme used in the SPS service in IRNSS. An exponential function is used to generate sine and cosine data samples in I/Q format. The calculated Doppler frequency value is fed into the exponential function along with the carrier frequency to generate a modulated complex signal in the form of I/Q data.

The above operations are performed for each valid list of satellites for the given position. The signal strength of individual satellite is defined by multiplication factor 'A_i' in Eqn. (1)-(2), which depends on the azimuth and elevation angles of the satellite with respect to receiver. The signal parameters update rate is 1 Hz; for every second, signal parameters are calculated

concerning the satellite position.

The resultant file can be saved in a local drive or used with a software receiver to obtain the given position at the receiver.

3.1.7 Generation of GNSS RF Signal

In practical applications, to analyse any GNSS receiver performance for a particular error, the generated signal must be the same as the real-world signal, which is an RF signal. To generate an RF signal, any standard Software Defined Radio (SDR) board with basic specifications capable of producing an RF signal with a digital baseband signal as input can be used. The selection criteria for choosing an SDR board is that the generating signal frequency band falls into its operating frequency range, with adequate bandwidth, suitable transmission power level, and sufficient sampling frequency. The bladeRF board is chosen due to its specifications, which include an operational frequency range of 47 MHz to 6 GHz, a bandwidth of up to 56 MHz, and sample rates of up to 61.44 MHz. The bladeRF board's onboard reference clock operates at 38.4MHz and includes an external reference clock input, which adds the capability of using an external reference clock. The board supports USB 3.0 for data connectivity. Additionally, bladeRF is inexpensive compared to other SDRs and easy to operate via simple operating commands. The bladeRF picture is shown in Fig. 5.
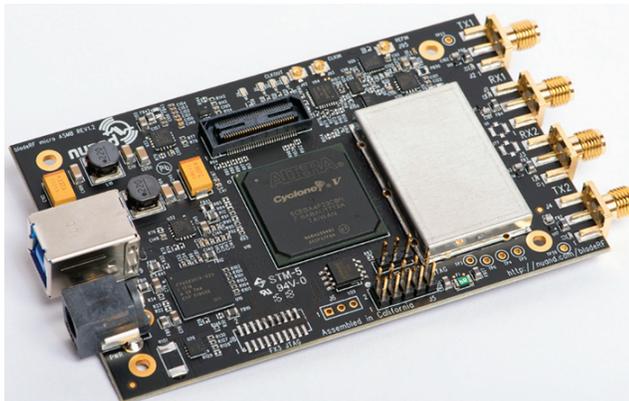

Figure 5. bladeRF board.[29]

The bladeRF board is connected to the computer via a USB 3.0 interface to pass the signal parameters like center frequency, digital I/Q data file (which is generated by the proposed simulator), gain, and sampling frequency using specific commands on the bladeRF software interface.[29] The digital baseband signal I/Q data samples are then passed through the USB 3.0 interface provided sampling rate. The bladeRF board generates an RF signal at the given carrier frequency; for the IRNSS L5 band, it is 1176.45 MHz as per the standard value given in the ICD document[16]. The signal generated with bladeRF can be connected to the antenna input port of the GNSS receiver via injection mode using an RF cable, preventing unauthorised transmission (disabling the antenna power from the receiver, as the most of the receivers
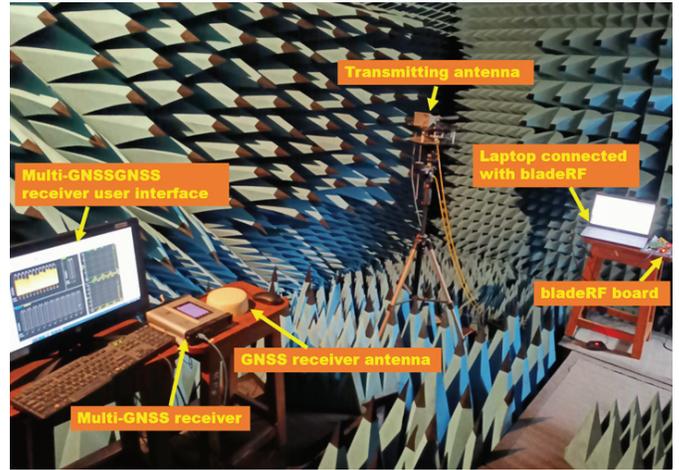

Figure 6. Experimental setup.

use an active antenna). To transmit the GNSS signal in an RF protected environment, a suitable antenna can be connected to the bladeRF output port.

The experimental setup is placed in RF protected anechoic chamber, as shown in Fig. 6, to avoid unauthorised GNSS signal transmission in the actual band. The bladeRF board is connected to the laptop, which consisting the digital I/Q data signal file generated by the proposed simulator. The file path and other signal parameters are passed to the bladeRF board. The horn antenna is connected to the RF output port of the bladeRF board, and the transmitted power is set to -90 dBm. The transmitted signals are picked up by a multi-GNSS receiver antenna, and the receiver gets a positional lock on it as expected.

3.2 Generation of IRNS S1 Band

IRNSS S1 band signal generation steps (Algorithm. 1) are the same as the L5 band. However, the C/A code sequence and carrier frequency differ for L5 and S1 bands.

3.2.1 C/A Code Generation for IRNSS S1 Band

Generation logic for C/A code is the same as the L5 band, but the initial bits for the $G2$ shift register are different to get different PRN codes for the S1 band (refer to Table. 2).

3.2.2 Carrier Signal

Carrier signal frequency for the IRNSS S1 band is 2492.028 MHz. Except for the generation of C/A codes and the frequency of the carrier in the S1 band, the procedure is the same, as explained in section 3.1.1.

3.3 Global Positioning Satellite System (GPS)

In this paper, generation of GPS L1 band, SPS signal is considered for the implementation, due to the fact that it is free to use with C/A codes that are known, but L2 band Precision

Table 2. IRNSS S1 initial $G2$ bit sequence for SPS signals

PRN ID	1	2	3	4	5	6	7
Initial bits G2	0011101111	0101111101	1000110001	0010101011	1010010001	0100101100	0010001110

(P) code is encoded signal, and only authorised users can access the services[17, 30].

3.3.1 GPS L1 Band Signal Generation

The fundamental signal generation part is the same as discussed in section 3.1.1-3.1.7; the difference is in C/A code generation, navigation data subframe structure, and carrier frequency. The steps involved in the signal generation are as given in Algorithm 1.

3.3.2 C/A Code Generation

GPS consists of 32 PRN codes for 32 different satellites. The logic diagram for the generation of GPS C/A code is shown in Fig. 3. Different combinations of $G1$ and $G2$ shift registers are given in Eqn. (3) to produce unique PRN codes for each satellite as given in the standard document[17].

4. MULTI-GNSS SIGNAL GENERATION

All three (IRNSS-L5, IRNSS-S1, and GPS-L1) bands of GNSS signals are generated for the user-defined scenario. Multi-GNSS signals are synchronised at the sampling frequency level.

The block diagram in Fig. 8 depicts the complete form of sections 3.1 and 3.3. The number of satellites in view is calculated using azimuth and elevation angles information for the GPS and IRNSS constellations based on the user-defined scenario location information and time. Each satellite, pseudo-range, code, and carrier phase values are calculated, and navigation data is generated by using given ephemeris data. The satellite signals generated for the IRNSS dual-band and GPS-L1 band are combined, and the resultant signal is in the form of I/Q data. The generated I/Q signal can be connected to three different SDR boards to get RF signals for three different
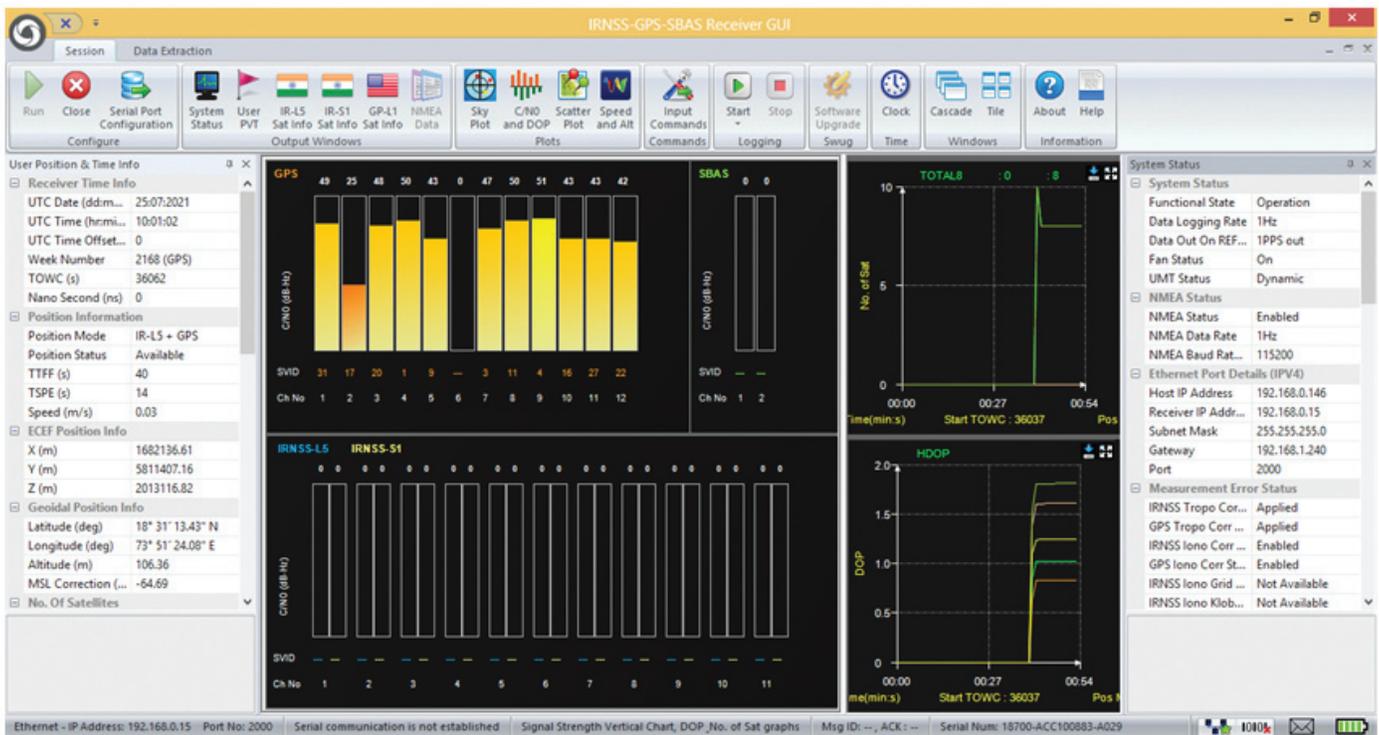

Figure 7. GPS-L1 band signal position lock on commercial receiver.[27]

3.3.3 Navigation Data

The GPS RINEX data file contains satellite ephemeris parameters used to generate a 1500-bit long master frame. The RINEX file ephemeris parameters are converted according to the timing information and standards of subframe structure. GPS subframe parameters are given in Appendix-I.

3.3.4 Carrier Signal

GPS L1 carrier is a sinusoidal signal with a center frequency of 1575.42 MHz, as per the standard given in IS GPS document[17]

Signal generation is the same as explained in IRNSS-L5 band signal generation (Section 3.1.1-3.1.7).

The generated signal is received by a commercial Accord software and systems receiver[27]. In Fig. 7, according to the given input to the proposed simulator, the received GPS satellite signals and positional lock are observed.

band signals, provided the sampling rate, corresponding center frequency, and other parameters for each band. These three different bladeRF boards baseband reference clock is synchronized by master-slave triggering technique. On the other hand, this signal can be stored in the local drive and used at any time for repeated testing applications.

The generated I/Q data for 1200 seconds, at 5 MHz sampling rate connected to a GNSS receiver and obtained a position lock as per the given location with a Time To First Fix value of 67 seconds, as shown in Fig. 9.

5. APPLICATIONS

GNSS software-based simulators have a wide range of applications in the defence sector and research[1,2,19,20,31], with advantages like repeatability, reconfigurability, controllability, and flexibility.
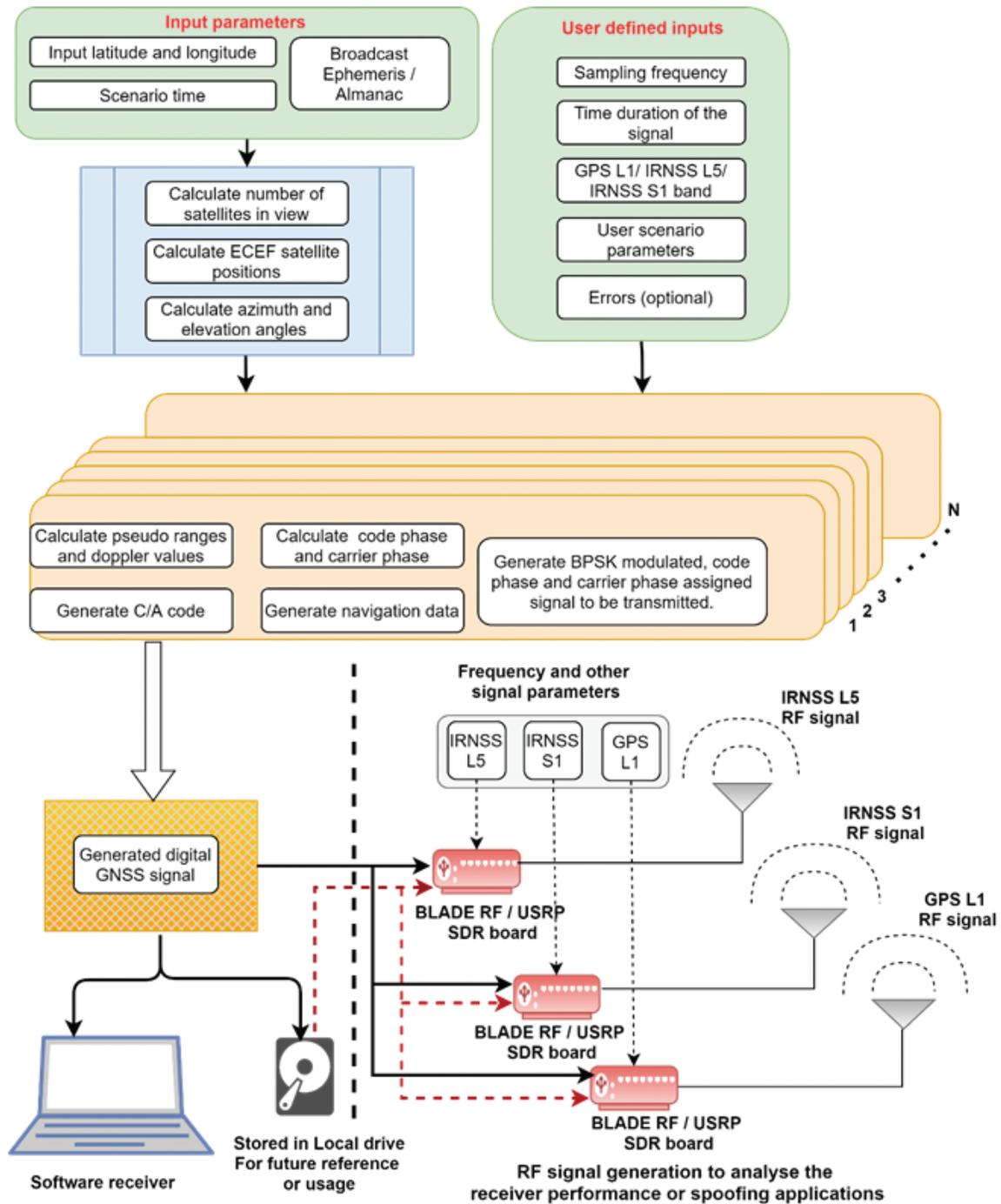
Figure 8. GNSS simulator design block diagram.

5.1 Spoofing Applications in the Defence Sector

In this case, the spoofing GNSS signals are generated using the proposed simulator for the specific user-defined positional information and timing. The generated I/Q data file is fed to the bladeRF board to generate an RF signal. The transmitted GNSS signal is received by the receiver and perfectly decoded for the spoofed location by ignoring the original GNSS signals. In defence applications, this phenomenon can be used for GNSS spoofing as one of the Electronic Warfare techniques. The spoofing signals should have 1-3 dB extra power over the authentic signals at the receiving antenna[8]. Power levels and an appropriate antenna can be selected for spoofing applications based on the coverage range and surroundings. In this spoofing experiment, the GPS signal strength is set for -90 dBm connected to a horn antenna with isotropic gain 13 dBi.

In this paper, a spoofing signal is generated for the Delhi location by feeding the positional input of Delhi. A commercial u-blox receiver[32] is used for the spoofing test. Initially, it receives actual live GNSS signals and shows Pune's location. Following the activation of spoofed signal transmission by the bladeRF SDR board, the receiver began to display the spoofed location, as seen in Fig. 10.

Figure 9. Receiver lock position with IRNSS-L5 and GPS-L1 bands on multi GNSS receiver [27]
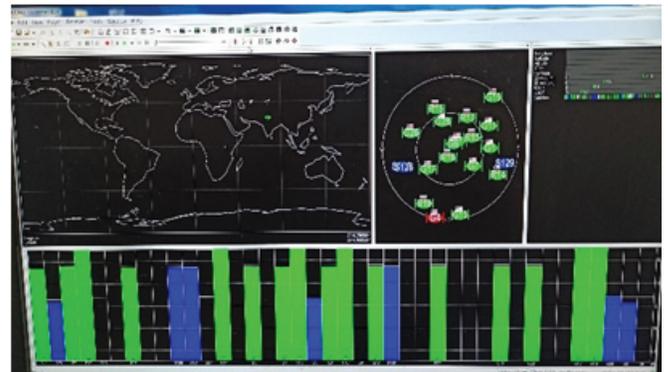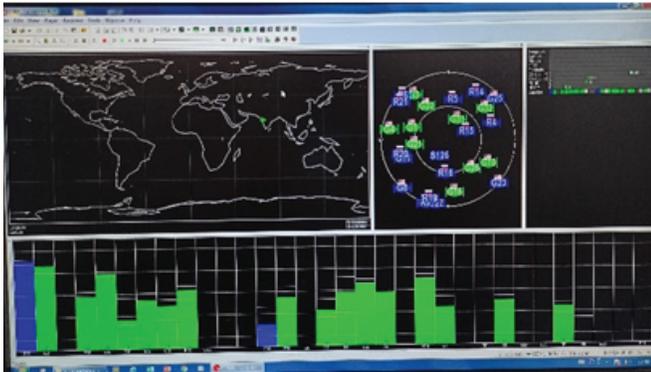

Figure 10: Spoofing on u-blox receiver[32] (a) Before spoofing-signal activated, receiver position with the live signal at live location Pune, and (b) After spoofing-signal activated, receiver position for the spoofed location Delhi.

5.2 Receiver Performance Analysis

One of the major applications of a software GNSS simulator is to assess the receiver performance analysis under user-defined error conditions, which can be achieved by the controllability of a simulator signal over different parameters. The proposed simulator can provide controllability on all the essential parameters at the subframe level. In addition, the proposed simulator allows for the investigation of receiver behaviour under specific ionospheric or tropospheric models. The intermediate stage data, such as the pseudo-range, code phase, and carrier phase values, can be recorded in the simulator and compared with the values produced by the receiver. It is possible to generate real-time scenarios, such as multipath scenarios[13,18] with different conditions, and channel models can be implemented and used to test the receiver performance with different tracking methods[8,11]. The other real-time possible errors can be modelled, and the same can be fed to the GNSS receiver to analyse receiver performance[9].

5.3 Development of New GNSS Signals

Software-based simulators are required for the research and development of new GNSS signals. These software-based GNSS simulators allow users to access all the individual parameters and signal generation logic modifications. The proposed simulator can be used to study and development of new GNSS signals. New modulation, multiplexing schemes, PRN codes, and different data subframe structures can be implemented to develop new GNSS signals, which can then be run on the software-based modified receiver to properly decode with suitable algorithms related to those used on the signal generation side[12].

6. CONCLUSIONS

The importance of GNSS simulators in research, starting with the study of different error performance in a GNSS receiver and progressing to the development of new satellite navigation

signals with improved performance for future applications. In this paper, IRNSS and GPS signals are generated, beginning with basic parameters calculations at the subframe level to RF signal generation with the help of standard documents as a reference, which have a wide range of applications in defence and research fields. The proposed reconfigurable software-based multi-GNSS simulator considers the IRNSS-L5, IRNSS-S1, and GPS L1 SPS bands for signal generation. The proposed hybrid GNSS simulator can be used as a software simulator that generates digital data as well as a hardware simulator to generate RF signals by using a general-purpose SDR board (bladeRF board). Generated signals are validated with different hardware and software receivers. The proposed simulator can be used as an alternative to expensive commercial simulators with the additional advantages of reconfigurability, repeatability, flexibility, and controllability. Significant application areas of the proposed simulator are discussed, including spoofing in the defence sector, receiver performance analysis, and the development of new GNSS signals.

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