m3 systems

StellaNGC
Plug & Play

GNSS Simulator Datasheet

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I. Introduction

This document is StellaNGC Plug and Play product datasheet. This simulator adds an abstracting layer to GNSS simulation to let the user focus on the main parameters of interests: **date, trajectory definition and GNSS constellations control**.

Applicable Documents

[AD. 1] StellaNGC® Plug and Play GNSS Simulator - Users Guide

[AD. 2] 2016 12 - M3 SYSTEMS - CGU Version GB

Reference Documents

[RD. 1] NI USRP-2950R Device Specification

[RD. 2] NI 5840 Device Specification 376626A-01 March 16, 2017

[RD. 3] NI 5841 Device Specification 378128B-01 April 6, 2020

[RD. 4] NI USRP-2954 Device Specification

Abbreviations

API	Application Protocol Interface
DUT	Device under test
ECEF	Earth-Centered, Earth-Fixed
FPGA	Field-programmable gate array
GNSS	Global Navigation Satellite System
GPS	Global Positioning Systems
GUI	Graphical User Interface
Hw	Hardware
ICD	Interface communication document
IMU	Inertial Measurement Unit
LLA	Latitude, Longitude, Altitude
M3S	M3 Systems
N/A	Not Applicable
OEM	Original Equipment Manufacturer
P&P	Plug and Play
PXIe	PCI eXtensions for Instrumentation
RAID	Redundant Array of Inexpensive Disks
RF	Radio Frequency
RP	Record & Playback
SDR	Software Defined Radio
Sw	Software
TBD	To Be Defined
TCP/IP	Transmission Control Protocol/Internet Protocol
TDMS	Technical Data Management Streaming: NI owner file format
OCXO	Over Controlled Cristal Oscillator
OS	Operating System
VST	Vector Signal Transceiver
SV	Space Vehicle

II. System Overview

StellaNGC Plug & Play is based on a layered architecture. The GNSS simulator provides simulation data to the user and external systems, at different levels (RF, IQ, GNSS Raw data, trajectory).

Trajectory layer (software) oversees trajectory & attitude computing and provides the mobile's motion (3D position, speed, acceleration, radial position, radial speed and radial acceleration), normalized at the iteration rate (user available in real-time and in a post processing file format).

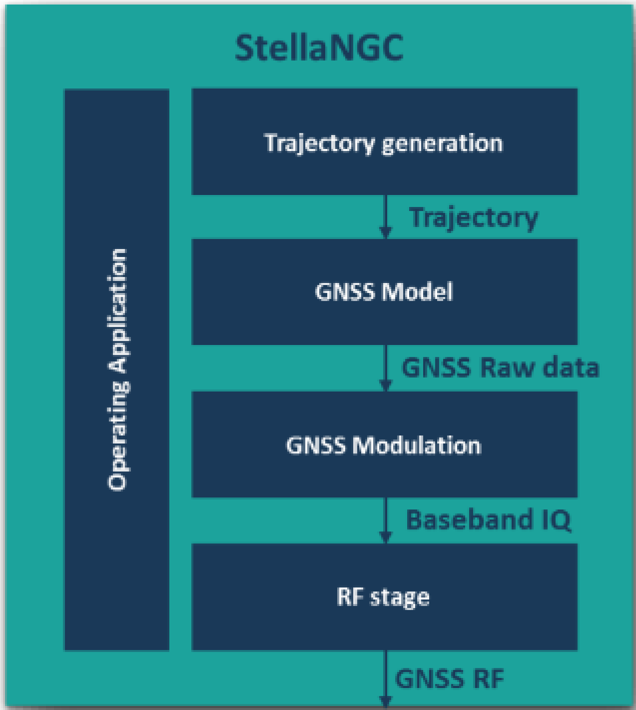


Figure 1 StellaNGC P&P System Overview

GNSS model layer (software) oversees the computing of satellite motion and broadcasted message for a specific date. Then, based on the simulated receiver trajectory, it computes the GNSS raw data such as SV pseudo range, doppler and navigation message (user available in real-time and in a post processing file format).

GNSS Modulation layer oversees generation of the GNSS signal-in-space in real time as defined in the ICDs described in the hereunder table.

RF layer oversees transmission of the GNSS signal on the appropriate L-band frequency.

Hereunder the different available GNSS constellations and their ICD are presented:

III. Constellations

StellaNGC P&P covers the simulation of the following signals withing their respective ICDs:

Constellation	Frequency/Signal	ICD Version
GPS	L1-C/A	IS-GPS-200 - Revision L, May 14th, 2020
	L1P Y-codeless	IS-GPS-200 - Revision L, May 14th, 2020
	L1-C	IS-GPS-200 - Revision L, May 14th, 2020
	L2-P Y-codeless	IS-GPS-200 - Revision L, May 14th, 2020
	L2-C	IS-GPS-200 - Revision L, May 14th, 2020
	L5	IS-GPS-200 - Revision L, May 14th, 2020
GLONASS	G1-C/A G2-C/A	"GLONASS Interface Control Document", v5.1, 2008
GALILEO	E1-BC E5a E5b E6	"Signal In Space Interface Control Document", Issue 1.3, 2016
QZSS	L1-C/A L2-C L5	"Interface Specification for QZSS", Japan Aerospace Exploration Agency, v1.5, March 27th 2013
BEIDOU	B1i B2i	BeiDou Navigation Satellite System Signal In Space Interface Control Document Open Service Signal (Version 2.1)
	B3i	BeiDou Navigation Satellite System Signal In Space Interface Control Document Open Service Signal B3I (Version 1.0)
SBAS L1	EGNOS WAAS MSAS	"The European Organization for Civil Aviation Equipment - Signal Specification for SBAS L1/L5" - Draft v.3, May 2008Message: " Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment", Appendix A, 2006

IV. Interfaces

StellaNGC P&P software is deployed on a classical Windows Operating System. As a standard software, the user can launch StellaNGC P&P from a shortcut and operate it through a **Graphical User Interface**.

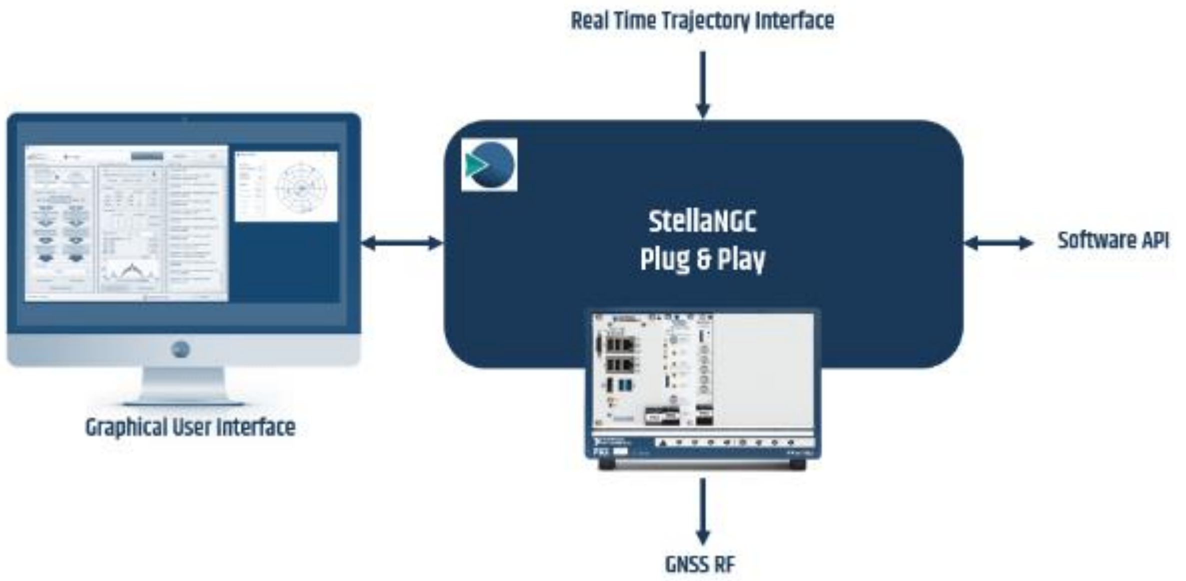


Figure 2 StellaNGC P&P Main Interfaces (GNSS RF may vary)

Additionally, it is possible to integrate StellaNGC P&P within a larger test bed. In this case, an **API** (Application Programming Interface) is available. StellaNGC P&P can be controlled and monitored through TCP/IP commands. A dedicated port is used for the closed-loop capability (where input trajectory data is expected).

From a hardware point of view, the simulator can be interfaced with a **hardware trigger**, which allows to launch a GNSS simulation synchronously with any external system with a nanosecond level precision. It also has a 1PPS signal generation port and clock facility ports (External/internal 10MHz clock).

V. StellaNGC Plug & Play Capabilities (Standard Mode)

StellaNGC P&P has two operational modes:

- StellaNGC P&P Standard Mode
- StellaNGC P&P Advanced Mode

The standard mode is easy to use and operate but offers limited simulation capabilities, whereas the advanced mode is a higher-end operational mode, which allows more flexibility in the trajectory definition and GNSS modelization. The hereunder sections describe the performances of StellaNGC P&P under its standard mode.

For more information on the advanced mode, please refer to paragraph VI.3

V.1 Trajectory Definition Capabilities (in Standard Mode)

V.1.1 Open Loop

The trajectory is defined in configuration mode (before the beginning of the simulation).

The following trajectories and file formats are covered by StellaNGC P&P.

Terrestrial

– Parametric Geodetic (static and dynamic)

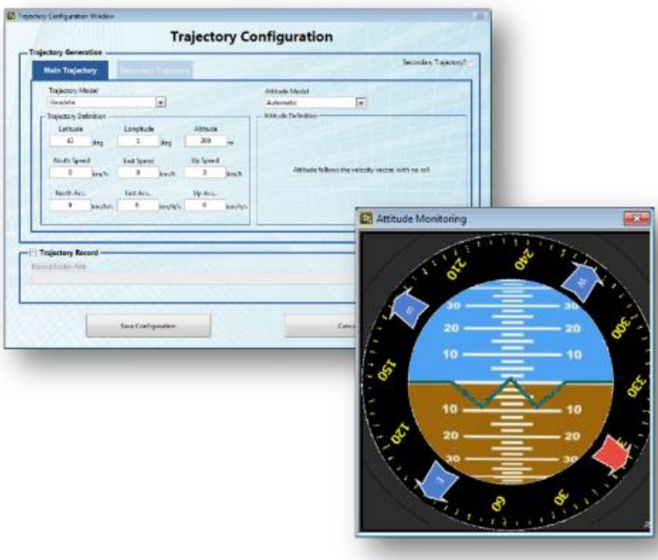
Compatible File Import

– NMEA (GGA)
– KML

Mobile Attitude Configuration

– Automatic Attitude Configuration (ground course)

Figure 3 GUI for Trajectory Configuration and Attitude Monitoring



V.1.2 Closed Loop

The user defines the TCP/IP port used by StellaNGC P&P to receive the motion information. The provided data information can be basic or detailed:

Position stimuli, including one or several parameters out of:

- Used Reference for position (among ECEF, ECI, LLA_WGS84, LLA_MSL)
- Used Reference for dynamics (among ECEF, ECI, NED, Front/Right/Below)
- Position, Speed, Acceleration, Jerk

Attitude stimuli, including one or several parameters out of: Attitude, Angular Velocity, Angular Acceleration, Angular Jerk

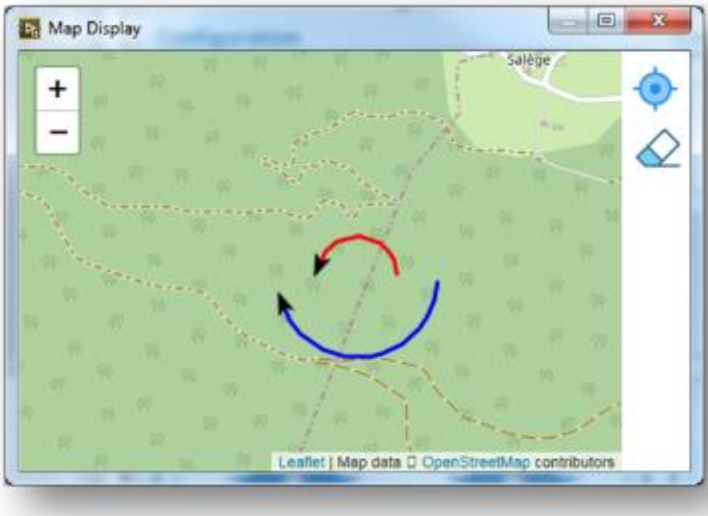


Figure 4 Multi-trajectory Map Display

V.1.3 Multi-trajectories and antennas

The user can define up to four different and independent trajectories.

The trajectory can be monitored during simulation either by:

- Map display: Online/offline (Based on OpenStreetMap)
- Live Attitude Indicator

V.2 GNSS Model Capabilities (in Standard Mode)

Each of the following elements can be configured by the user in StellaNGC P&P.

Immediate Simulation Date Changes

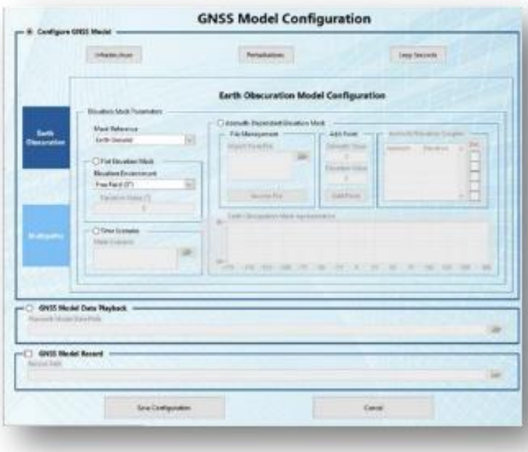
Based on the configured date, the GNSS Model automatically handles both the GNSS ground and space segment configurations (navigation messages and satellite motion).

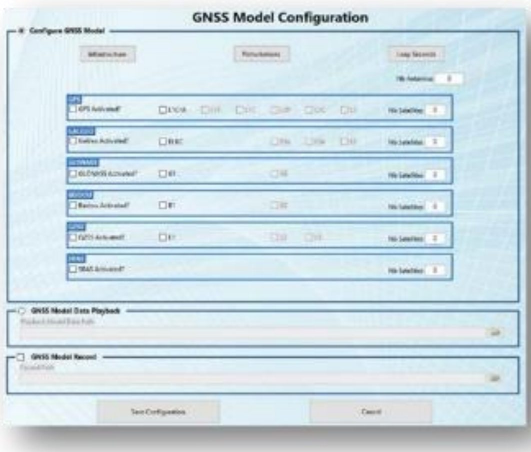
Channel Emulation

- Automatic Doppler, free space losses computation
- Automatic simulation of atmospheric effects (ionosphere/troposphere)
- Earth Obscuration Model (elevation mask static or dynamic)
- Automatic simulation of realistic satellite & receiver antenna

GNSS Control

- GNSS constellations control
- GNSS signals control (To simulate tunnel effects for example)
- GNSS number of satellites: by default, StellaNGC is configured to generate 8 satellites per constellation. However up to 12 satellites can be generated if required.





VI. StellaNGC Plug & Play Add-Ons

StellaNGC P&P is a fully modular and flexible software. Based on your user story, you can select amongst a wide range of features the ones that are needed for your project.

Those Add-Ons and are described in the sections below.

VI.1 Multi-band generation

Both GPS L1C/A and GALILEO E1-B/C are included in StellaNGC P&P's entry offer. If needed, the user can easily implement any of the below additional constellations and/or signals through a simple license extension.

GPS	L1P Y-codeless L1-C L2-P Y-codeless L2-C L5
GLONASS	G1-C/A G2-C/A
GALILEO	E5a E5b E6
QZSS	L1-C/A L2-C L5
BEIDOU	B1i B2i B3i
SBAS L1	EGNOS WAAS MSAS

VI.1 Closed-Loop or Hardware-in the-Loop (HIL)

HIL testing allows the user to bridge the gap between using MIL (models-in-the-loop or software component models) and building a real mobile for each test engineering lab. It is defined as the ability, from a whole test bench point of view, to emulate the virtual environment of a DUT.

StellaNGC allows the user to provide a trajectory input from an external system, and thus integrate GNSS testing to a wider and more complete test bed.

Moreover, the external system which feeds StellaNGC with the trajectory can either be a customer made test platform or one of the many test environments used in the industry.

For instance, StellaNGC P&P is easily interfaceable with IPG CarMaker & TruckMaker, Monodrive, AVSimulation, CANAlyzer, Canoe, Flight simulators, etc…

This interfacing is based on a StellaNGC custom device for Veristand. The figure below shows how StellaNGC can be interfaced with IPG CarMaker in HIL mode.

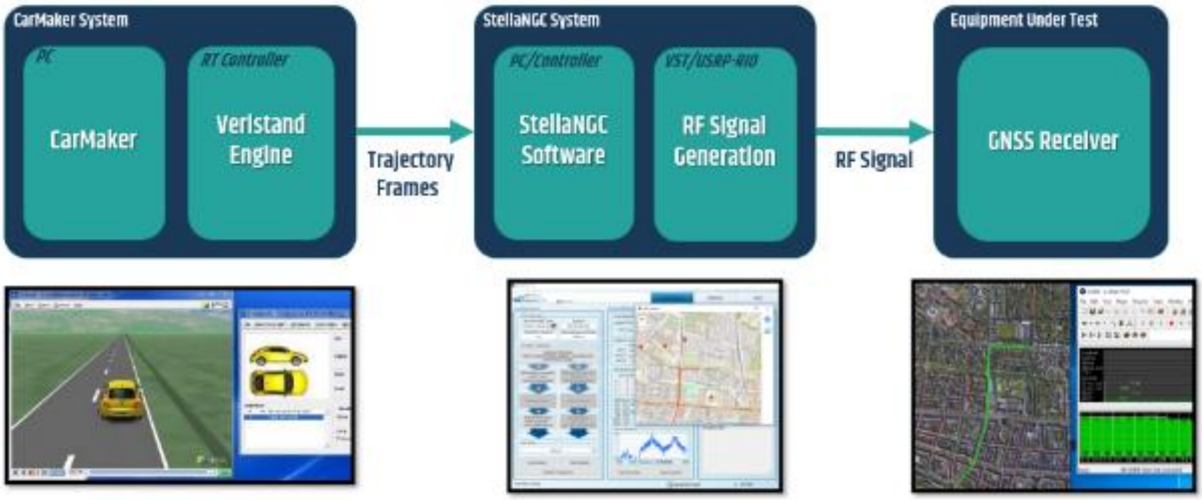


Figure 6 StellaNGC Integration to IPG CarMaker

VI.1 Satellite-Based Augmentation System (SBAS)

GNSS performance can be improved by regional Satellite-based Augmentation Systems. SBAS improves the accuracy and reliability of GNSS information by correcting signal measurement errors and by providing information about the accuracy, integrity, continuity, and availability of its signals.

In StellaNGC P&P, there are two ways to simulate SBAS signals. Either by directly providing the navigation message content (EMS) or by providing appropriate ephemeris files. The EMS method is applicable for EGNOS only whereas SBAS standalone can be used to simulate any SBAS satellite compatible with the "Aeronautical Telecommunications Annex 10 To The Convention On International Civil Aviation".

EGNOS EMS Simulation

In StellaNGC P&P, the simplest way to simulate EGNOS satellite is by providing an EMS file. EMS stands for EGNOS Message Server. This file can be found on an FTP link provided and maintained by the ESA: http://www.egnos-pro.esa.int/ems/index.html

SBAS Standalone Simulation

In StellaNGC P&P, the main broadcasted SBAS parameters can be computed when SBAS is used without EMS files (i.e. the GNSS Model computes the navigation message). To do so, it is required to provide an SP3 file for the space segment while providing the related RINEX file for the ground segment.

VI.2 Real Time Kinematic (RTK)

RTK is a satellite positioning technique based on the use of measurements of the phase of the carrier waves of the signals transmitted by GNSS systems. A reference station provides real-time corrections to achieve centimeter-level accuracy.

In StellaNGC P&P, the user can configure each of: **position, attitude, and Rx Antenna of the base station**

- Base station Position: position configured in LLA format.
- Base station Initial Attitude: The attitude of the base station directly represents the attitude of the transmitting Antenna of this base station. This Attitude is configured in rad for each parameter Roll, Pitch and Yaw in ENU Reference Frame (0, 0, 0 points towards East)
- Base station Attitude Velocity: Allows to configure the attitude variation in time of each base station. This variation can be configured in rad/s for each parameter Roll, Pitch and Yaw in ENU Reference Frame.
- Antenna Pattern Diagram Configuration: Allows to configure the Rx antenna gain pattern of each base station by providing a formatted file containing the 2D Table of the Attenuation function of the Elevation and the Azimuth.

RTCM Frames

StellaNGC allows to generate RTCM frames following the RTCM STANDARD 10403.3 Differential GNSS Services - Version 3. The following RTK messages are covered:

Frame Number	Frame Description
RTCM 1005	Stationary RTL reference station ARP
RTCM 1006	Stationary RTL reference station ARP with antenna height
RTCM 1074	GPS MSM4
RTCM 1084	GLONASS MSM4
RTCM 1094	Galileo MSM4
RTCM 1104	SBAS MSM4
RTCM 1114	QZSS MSM4
RTCM 1124	BeiDou MSM4

VI.3 Advanced Mode

StellaNGC P&P Advanced Mode is a higher-end operational mode, which allows more flexibility in the trajectory definition and GNSS modelization.

VI.3.1 Trajectory Definition Capabilities (in Advanced Mode)

The trajectory is defined in configuration mode (before the beginning of the simulation).

The following trajectories and file formats are covered by StellaNGC P&P in the Advanced Mode.

Terrestrial & Space

- Parametric Geodetic (static and dynamic)
- Circular motion
- File import
- Keplerian defined

Compatible File Import

- NMEA (GGA)
- KML
- Formatted file (ECEF frame)

Mobile Attitude Configuration

- Terrestrial/Aerial Automatic Attitude Configuration (ground course)
- Space Automatic Attitude Configuration
  - Earth Pointing
  - Anti-Earth Pointing
  - Sun-pointing
- Parametric Attitude configuration

VI.3.2 GNSS Model Capabilities (in Advanced Mode)

Through the advanced mode, GNSS experts can model very advanced scenarios to test feared events. Many errors can thus be injected at will by the user:

- Error injections on one or more satellite clock
- Error injections on one or more satellite information
- Satellite in fault stops transmitting during simulation

The advanced mode also allows the user to configurate the following aspects of the GNSS model:

GNSS Ground Segment

User can control what is going to be broadcasted as a navigation message by the simulated SV. User can auto-populate messages from an ephemeris file (such as RINEX)

GNSS Space Segment

User can define the simulated SV motion, antenna, generation power. The SV definition can be auto populated from an ephemeris file (such as RINEX).

Atmospheric Perturbations

Ionosphere Perturbations: Klobuchar, user-defined file

Troposphere Perturbations (MOPS)

Obscuration

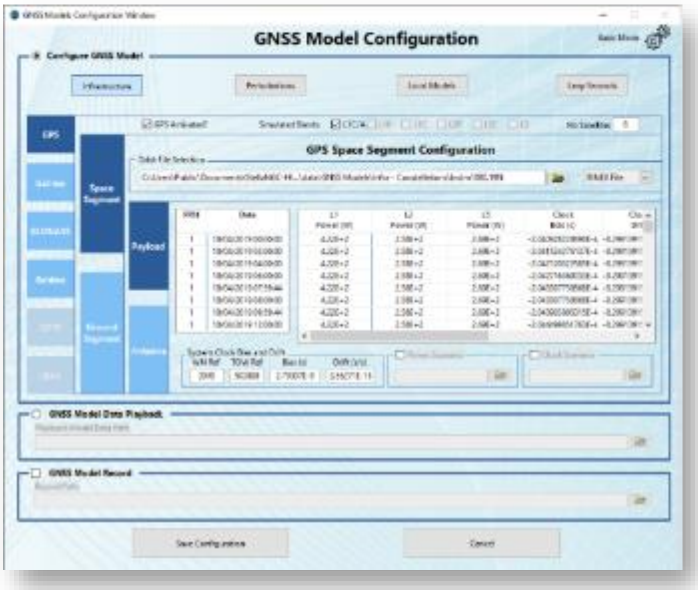
Earth Obscuration Model Elevation Mask

Mobile Solidary Obscuration Model

GNSS Local Model

Rx Antenna Gain pattern and polarization, off-axis, antenna mis-pointing

Multi-antenna



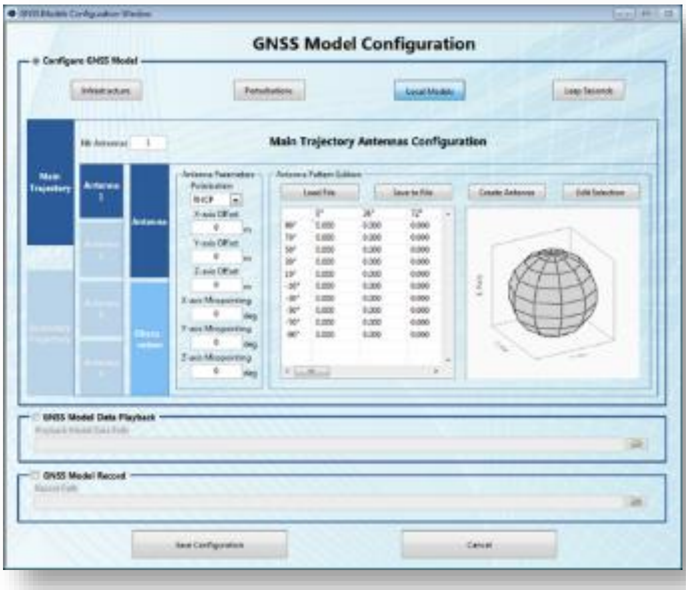


Figure 7 Advanced GNSS Model Configuration

The tables below break down major performance differences between the standard mode and advanced mode, in terms of trajectory definition and GNSS simulation:

Trajectory Definition		
	StellaNGC P&P Advanced Mode	StellaNGC P&P Standard Mode
Geodetic	Yes	Yes
NMEA, KML	Yes	Yes
Circular	Yes	No
Formatted file	Yes	No
Keplerian	Yes	No

GNSS Simulation		
	StellaNGC P&P Advanced Mode	StellaNGC P&P Standard Mode
RINEX FREE Configuration	No	Yes
Channel Power Control during Simulation (Tunnel effects)	Yes	Yes
GNSS Raw Data Record & Playback	Yes	Yes
IQ Logging	Yes	Yes
NAV Message Configuration (Health, clock, atmosphere, user range accuracy, CRC)	Yes	No
Ephemeris, Almanac, SP3 (for errors injections while simulating)	Yes	No
Atmosphere Models configurability	Yes	No
Tx Antenna Configuration	Yes	No
Tx Antenna Model	Yes	No
Rx Antenna configurability	Yes	No
Payload Power configurability	Yes	No
Payload Power Scenario	Yes	No
Leap Seconds Configuration	Yes	Yes

VI.4 Multipaths

In GNSS, Multipaths are the main sources of error as they cause changes in a random way, without correlation with space and time. In StellaNGC P&P, 3 types of multipath models are proposed. For each of them, the GNSS Multipath Raw data will be produced at the GNSS Model layer.

User Defined Model

It allows the user to specify through a scenario file each NLOS parameter:

- Time of appearance (in simulation time)
- Additional Delay
- Additional Doppler
- Additional Phase
- Attenuation
- Duration

This model is a first level interface to generate GNSS multipath. Several use cases are covered with this approach, such as:

- System interface to external software modelling multipath
- Validation scenario to test correlators. In this case, created multipath does not have to be representative but its characteristics shall be user-controllable

Statistical Model

StellaNGC P&P comes with 3 statistical laws for **predefined configuration** representing 3 environments:

- Urban area: this environment is characterized by tall obstacles (buildings, trees, and light spots). This induces many multipaths in addition of masking LOS signals.
- Semi-urban area: this environment is characterized with mid-tall buildings and trees inducing partial masking and GNSS reflection.
- Urban area: this environment is characterized by few small buildings and some trees inducing low masking and few NLOS

Custom defined statistical models can also be implemented in StellaNGC P&P.

Figure 8 Urban, Semi-urban and Rural Area Ground View

3D Scene Model

This model will output the NLOS parameters based on ray tracing computation with a 3D synthetic scene.

The GNSS signal propagation in constrained environments is disrupted by two intrinsic phenomena:

- Obstacles (e.g., buildings, moving objects, receiver's carrier, etc.) which hide the signal, induce shadowing effects and therefore, decrease the availability of the system.
- Interactions between the signal and the environment generates multipath (reflections, diffractions, transmissions…) that lower the accuracy of the system and weaken the receiver power (fading effects)

To address this topic, StellaNGC can be interfaced with **OKTAL SE-NAV**. This software deterministically simulates the propagation of a GNSS signal in a 3D virtual scene.

On the hereunder example: White rays - direct GPS paths as seen by receiver Blue, green and red rays - multipath signals

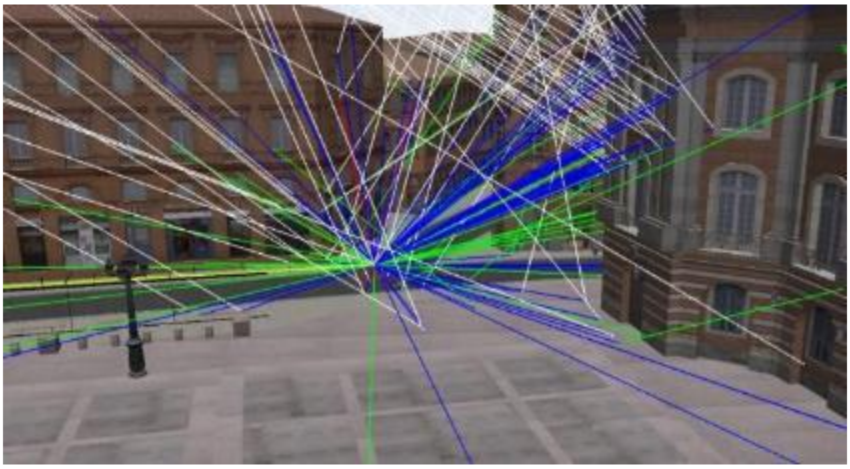


Figure 9 SE-NAV Simulation in Downtown Toulouse

VI.5 Interferer Generation

StellaNGC provides the capability to simulate realistic interferer environment through configuration of geo-referenced beacons. Each beacon can be configured in terms of emission parameters from transmission patterns to interferer type, but also beacon position and orientation. StellaNGC also supports both control and monitoring of interferer signals and beacons during simulation.

Following interferers can be simulated on each beacon:

- **DME/TACAN** Distance Measurement Equipment and TACtical Air Navigation respectively - are pulsed emitters that are used to evaluate the distance between a moving vehicle (e.g. airplane) and the emitting beacon
- **JTIDS** The Joint Tactical Information Distribution System (JTIDS) is an advanced radio system that provides information distribution, position location and identification capabilities in an integrated form for military operations
- **MultiTone/ILS** The Instrument Landing System (ILS) is a multitone signal that provides a civilian approach and landing guidance system
- **NLMF** Non-Linear Frequency Modulation signals
- **Radar** RAdio Detection And Ranging are used to detect and locate all the targets (cooperating or not) in a specified air domain by emitting electromagnetic pulses and analyzing the probable echoes due to the reflection on the targets
- **Spread Spectrum** combination of BPSK/DSSS/FHSS/THSS signals
- **VOR** VHF Omni Directional Radio Range (VOR) is a type of short-range radio navigation system which provides aircraft with a receiving unit to help them determine their position and stay on course by receiving radio signals transmitted by a network of fixed ground radio beacons

Figure 10 Map Display of DOPPLER Interferer

VI.6 Meaconing Spoofing

The main principle of meaconing spoofing is to delay GNSS signals and add it to real ones to spoof them. To simulate this type of spoofing, StellaNGC P&P has the capacity to delay from millisecond scale down to the nanosecond scale a simulation signal replica to add it to the simulated real signal.

This spoofing technique has been tested on a real GNSS receiver Septentrio PolaRx4. A fifteen-minute scenario has been created during which eight non-spoofed satellites are generated. The scenario is divided in two phases as follows:

- Between 0 second and 300 seconds, no satellites are spoofed
- Between 300 seconds and 900 seconds, the meaconing spoofing is activated

The figures below give respectively the two average positions obtained during the two phases of the scenario and the evolution of the position error.

The position estimation is deeply degraded when the spoofing is activated. Therefore, its effect can be clearly seen on the receiver.

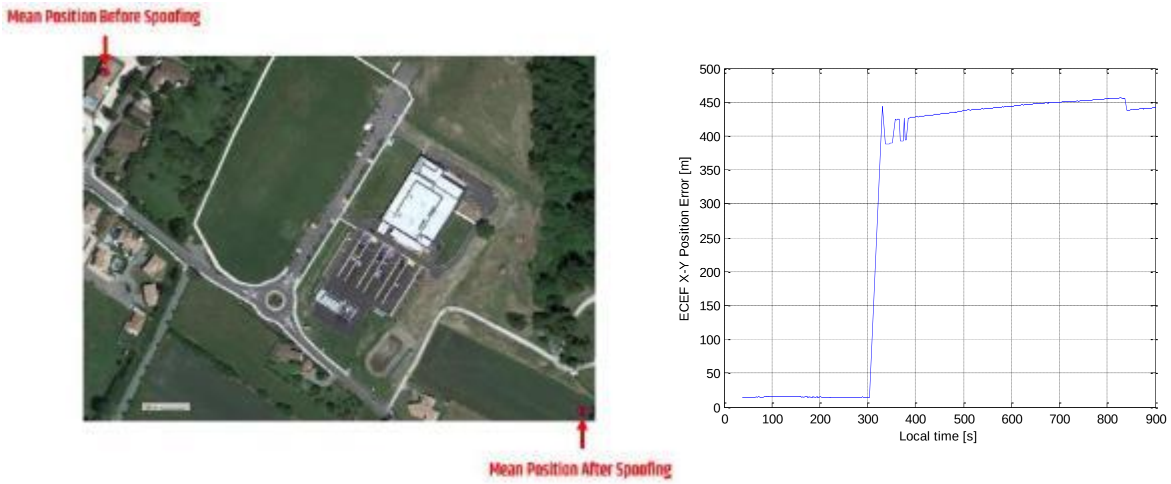


Figure 11 Spoofing Application with StellaNGC

VI.7 IMU Sensor Simulation

To address hybridization challenges, StellaNGC P&P implements an Inertial Measurement Unit (IMU) sensor simulation. The IMU sensor embeds 2 types of sub-sensor simulation: gyroscope and accelerometer. Both sensors' models can be constructed through the definition of their bias, scale factor, noise, and range effect models for each axis.

Figure 12 IMU Model Configuration

For hybridization use case, this option allows the generation of the IMU sensor output. Two use cases are covered. The first case is software-only where the hybridization algorithm to be tested is stimulated by IMU sensor simulation digital flow and GNSS raw data flow. It is illustrated hereunder.

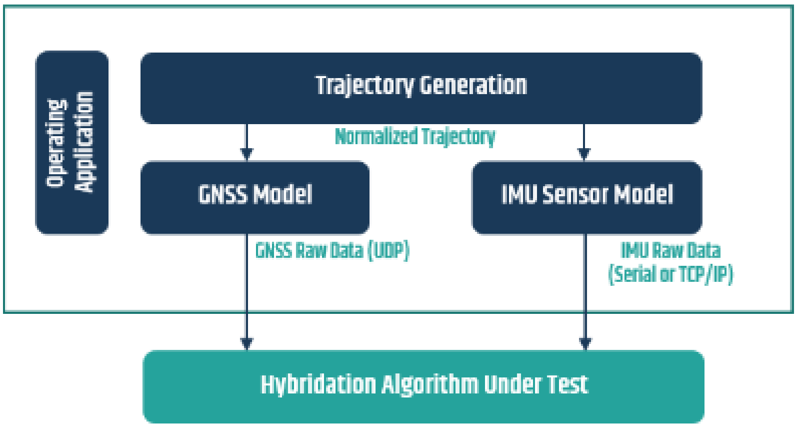


Figure 13 IMU Sensor Simulation - Software Only

The second use case is for testing hybridization algorithms when stimulated by both IMU sensor digital flow and GNSS sensor raw data flow. This GNSS receiver computes the raw data from the GNSS RF simulation. The advantage is the capability to inject the GNSS sensor accuracy into the test bed.

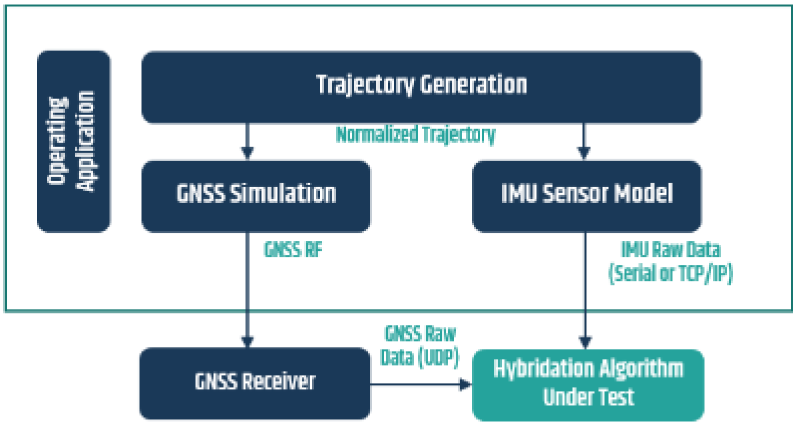


Figure 14 IMU Sensor Simulation - GNSS Receiver

VI.8 Other Add-Ons

100Hz Iteration Rate

With the StellaNGC Base Offer, the trajectory update rate can be configured up to 10 Hz. With this option the update rate can be configured up to 100 Hz.

Additional Trajectory extension

This option enables the ability to handle two independent trajectories at the same time within the same simulation (e.g., with the same GNSS space segment). This option requires a dedicated RF target for each of the trajectories.

2 or 4 multi-antenna extension

With this option, it enables to simulate co-localized antennas. This option requires a dedicated RF target for each of the antenna.

SV Channel Extension

This option allows to switch from 8 channels per constellations to 12. This option is recommended in aircraft and spatial applications. In most automotive applications, 8 channels per constellation are enough.

Exporting and Storage of I/Q Data

Data is stored in a tdms format, and an external tool allows conversion to binary IQ data.

VII. Hardware Compatibility

StellaNGC is compatible with the RF targets described in the below sections. In addition to RF targets, it is required to have a complete system with a Controller (such as NI PXIe-8160 or a standard PC) which hosts the software and the related environment. For PXIe environment, a PXIe chassis such as NI PXIe-1092 will be required.

VST second generation

The NI-5840/5841 is the second generation of Vector Signal Transceiver from NI.

Direct outcome:

- 500MHz instantaneous bandwidth on L Band: One RF stage is needed for multi-frequency management.
- Calibrated target: the 5841 is factory-calibrated and can be yearly calibrated to ensure high end RF performance (e.g., IQ imbalance & frequency response)
- List of calibration item can be found here http://zone.ni.com/reference/en-XX/help/374564L-01/calexec/procedure_5840/

As an example, a possible standalone hardware configuration could be: NI PXIe-5841+ NI-PXIe-1092 + NI PXIe-8880 as shown hereunder. To address record and playback capability, an SSD PXie Card is added (reference on demand)

USRP-RIO

USRP-RIO is widely used as an entry RF-target for functional verification applications. We do support both NI-2950R 120MHz and NI-2954. This target generates multi-frequency GNSS on L Band (L1, L2 and L5). USRP-RIO can be used along with a PXIe chassis or a standard PC (PCIe link is used in this case).

Product distributed by M3 Systems France

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