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Testing Telemetry Systems, which use GNSS Satellite Navigation Systems

Achieving Reliable and accurate Results with RF Simulation of GNSS Signals

Karen von Hünerbein[1], *Werner Lange*[2]
Lange-Electronic GmbH
Rudolf-Diesel-Str. 29 a
D-82216 Gernlinden
kvhuenerbein@lange-electronic.de

Abstract Text:

Positioning, timing and navigation (PNT) with Satellite Navigation Systems like GPS, GLONASS, Beidou and Galileo are more and more widespread and used in very different types of applications including core telemetry applications. Global Navigation Satellite Systems (GNSS) receivers in Safety Critical Applications such as landing airplanes, Critical Infrastructure or Remote Sensing missions e.g. Earth Observing Satellites need to be very robust and reliable under a variety of environmental conditions, sometimes very harsh ones outside the atmosphere. Timing is critical in communication between satellite ground stations and the satellites, e.g. telemetry tracking and command, or communication protocols using Time Division Multiple Access.

Thus, it is crucial to test GNSS receivers thoroughly under a variety of different conditions, also extreme conditions like very high dynamics or unhealthy GNSS satellites.

For this purpose GNSS RF signal simulators are a versatile and flexible tool. The tests can be repeated as many times as necessary with identical conditions. Besides this a simulator offers complete control across the scenario, every single detail can be controlled and changed. In RF simulators comprehensive error models are available for satellite signals and clocks, satellite orbits and health flags, obscuration and multipath, atmospheric conditions, antenna characteristics, vehicle dynamics, leap seconds, jamming and aiding Inertial sensors. Each of them can be controlled individually. For some tests, like unhealthy satellites or future constellations RF, simulators are the only way for testing, as future signals, for example, are not available in live sky test.

In this paper, we will introduce the capabilities of GNSS simulators with a wide range of different error conditions and show several telemetry use cases.

Key words: GNSS RF simulation, timing, telemetry systems, GNSS system errors, GNSS vulnerabilities

Introduction:

GPS has revolutionized accurate worldwide 3D positioning, navigation and timing during the last 20 years and more global satellite navigation systems (GNSS) and satellite based augmentation systems (SBAS) are being developed continuously, like IRNSS (Indian Regional Navigation Satellite System) and SDCM (System for Differential Corrections and Monitoring, the Russian SBAS) [1]. GPS is used in thousands of applications worldwide, among them many telemetry systems transmitting GPS data remotely.

Telemetry applications of GPS / GNSS are for example:

- Earth observation satellites with GPS timing and attitude control
- computer terminals in banking with GPS timing
- Galileo pseudolite synchronization with GPS timing
- tele communication base stations with GPS timing

- Communication between satellite and ground station via TDMA (Time Division Multiple Access)
- power grids with GPS timing
- precision approach of a tanker vessel to an oil platform exchanging GPS position information
- automatic broadcasting of GPS positions, velocity and altitude by aircraft (ADS-B Automatic Dependent Surveillance Broadcast) to improve air traffic control
- automatic broadcasting of GPS/GNSS positions by ships (AIS – Automatic Identification System) to avoid collision in narrow sea straits,
- fleet management of trucks,
- emergency beacons for people, boats, e.g. (GPS enabled EPIRBS Emergency Position Indicating Radio Beacon), and cars (European e-call system),
- tracking of birds, e.g. white storks in Eastern Germany, re-broadcasting of GPS positions via the ARGOS satellite system for migration research

  only to name a few.

GNSS and telemetry applications

On the one hand, GPS is a telemetry and telecommand system (TT&C) in its own right, since remote signals from satellites more than 20.000 km away enable calculation of accurate positions, velocity and time, anywhere on or above the surface of the Earth. GPS space vehicles are controlled and maintained with telecommands and receive navigation messages uploads by the ground segment. This is true for all GNSS.

On the other hand, there is an ever increasing number of GPS/GNSS application in telemetry. GPS time serves in many ways to synchronize transmission and communication, between remotely located transmitter stations and mobile phone base stations.

In the aviation GATE, the Galileo Testbed around the research airport of Braunschweig, the transmitter stations, acting as Galileo pseudolites, are located in an inner ring of five pseudolites around the runways and an outer ring of 4 pseudolites with distances up to 50 km from the airport, and up to 100 km diameter. Each transmitter station is equipped with a GPS timing receiver. The transmitter stations of the outer ring are connected to a central control server via VPN, WiFi and the internet, the stations of the inner ring have an additional connection via Ethernet. In this setup, the GPS timing receivers manage to synchronize the transmitted Galileo signals to an accuracy of better than 1.5 nsec [2].

GPS based timing is also crucial for base-stations with coordinated transmissions of radio and television programs and mobile phone calls. They depend on precise timing, because they are using Time Division Multiple Access (TDMA), which allows several users to use the same channel, each with a different time slot. Time slots are 0.577 msec long and need to be timed precisely, or else they will interfere with each other [3]. This also applies to all other communication systems using TDMA, e.g. satellite ground control stations communicating with the satellite in orbit.

Generally, GPS and GPS/GLONASS navigation systems are widespread in all sorts of vehicles for positioning and navigation, and more recently also for new safety procedures.

In aviation, the ADS-B Automatic Dependent Surveillance Broadcast is being deployed to improve visibility of airplanes for air-traffic control and other aircrafts. This allows more efficient route planning and situational awareness improving overall safety. The ADS-B onboard unit determines the position, altitude and velocity of the airplane with GPS/GNSS and broadcasts the airplane data and identification via radio transmission. ADS-B becomes mandatory in Australia this year [5]. The ground infrastructure was introduced in the USA in 2014 and it is mandatory for all airplanes to carry the necessary on-board equipment by 2020 [6].

For ships, a similar system has been deployed, since 2000, the AIS – Automatic Identification System allows tracking ships, which are obliged to send their GPS position and identification to satellites, in order to help to avoid collision between sea vessels, e.g. ships in the British channel. A second goal is to inform neighbouring countries, which ships are present in their coastal areas. [7]

Low Earth Orbit satellites (LEOs) monitoring the Earth, need precise GPS positions together with other sensors in orbit to correctly geo-reference the image. GNSS data are part of this orthorectification process. [18]

Vulnerability of GPS signals

"GPS and GNSS signals are easy to interfere with, as they transmit very weak signals below the noise floor. The signals can be attenuated, delayed or disrupted by GNSS system errors, atmospheric disturbances, multipath reflections, jamming, which is intentional or unintentional, RF interference and by spoofing, deception signals or other replicate GPS/GNSS signals potentially misleading the GPS/GNSS receiver." [8,10]. The rebroadcast of GPS positions and timing can also be falsified or prevented by cyber attacks. "Until a few years ago, jamming and spoofing have been more of a theoretical problem, with little practical relevance. Recently, more and more evidence of real-life situations of the different types of disruptive factors have been detected." [8,9].

GNSS system errors include operation failure of satellites, orbit errors, timing errors, incorrect orbit data in the navigation message, or unhealthy satellites whose status is not correctly declared in the navigation message. All these events have occurred in real life in the last few years. In April 2014, most satellites of the GLONASS constellation were uploaded with the wrong ephemerides and the whole GLONASS constellation was unusable for more than 10 hours [13].

Why is Multipath a problem? The reflected GPS/GNSS signals take a longer path to the receiver. The receiver needs to decide which signals to use for the position fix, if choosing multipath signals for the calculation, the accuracy of the position calculation is reduced. [10].

In order to identify problems of GPS receivers with these error effects before they occur in the field and in order to solve issues with controlled procedures before a network of base stations fails to operate or before an airplane crashes, verification of GPS/GNSS devices is crucial, with thorough, controlled and repeatable test conditions.

Field tests versus simulation:

Testing equipment in the field with live sky signals is not repeatable, as the satellites move in orbit and the constellation, and thus the signal environment changes constantly.

"Verification of aviation GPS receiver equipment with real live sky signals can be very time consuming and expensive requiring many test flights, when field tests are the primary test method. Field tests are not always possible, for example for unusual vehicle motion or dangerous situations, like a pilot deviating from the route in low visibility conditions and coming close to a mountain slope." [11] .

Field tests are impossible for LEO Earth observation satellites, or any other space vehicle. Earth Observation satellites use GPS as an AOCS sensor (attitude and orbit control system) and for timing relative to UTC: Extensive, thorough testing must be performed on the ground before launch, or else the satellite could become useless in orbit.

"Field tests are not possible for special conditions required by the test standard **DO-229** for aircraft GPS receiver qualification and by the maritime test standard **IEC 61-108-1** for GPS shipborne receiver equipment, which require tests with unhealthy satellites to validate RAIM algorithms. In the field a test engineer, pilot, or seaman cannot call USNO and ask to switch off satellites, set them unhealthy, or corrupt a satellite's navigation data or "simply" set a time error." [11].

Recently in January 2016, a real life timing error has occurred with GPS satellites during decommissioning of SV-23, where several satellites transmitted a UTC timing offset of -13.7 µsec in the navigation message. This was too much for timing receivers in telecommunication base stations in central Europe, which went out of operation due to this error [14]. This is a typical case, where the error conditions can be best tested and repeated with a GNSS signal simulator.

"For aviation, one test in DO-229 prescribes a) an airplane to statically hover in one position 5000 m above the South Atlantic Ocean b) one satellite (out of the 4 satellites used to calculate DOP) to deviate from its orbit by a large distance. Both conditions cannot be met in a field test." [11].

"The number of operational scenarios that can be evaluated in field tests is typically severely limited by time and cost constraints [12]", especially when testing needs to take place in remote locations. When adding GLONASS, Beidou or Galileo "capability to a GPS receiver, receivers need to be revalidated to guarantee functionality under a variety of environmental conditions and to meet strict performance criteria of national and international aviation administrations" [11].

Strengths of RF simulators

The performance of a GPS or a Multi-GNSS navigation system can be evaluated in the laboratory using a GPS/GNSS RF Constellation simulator, such as a Spirent GSS9000 [11]. "These signal generators precisely emulate the RF signals of the navigation satellites as would be received by the device under test at a defined time and location. Simulation offers unlimited repeatability of tests, full control over all relevant error sources, the possibility to test as many locations as needed, without having to move the device under test. Simulation offers the possibility, to limit the number of satellites in view, to switch off one or several satellites, define deviations of a satellite's orbit," introduce pseudorange errors, set one or several satellites unhealthy, set time errors or corrupt satellites' navigation data. [11].

In addition, it is possible to recreate a historic GPS or GLONASS constellation. This allows the user to analyze the influence of past signal environments and identify algorithmic errors in GPS/GNSS equipment, which only occurred once under one specific constellation condition. At the same time, future signals and constellations can be simulated, e.g. a full GALILEO constellation, enabling receiver development ahead of the full operational phase of a GNSS. Both types of tests are only possible with a GNSS RF simulator.

Excellent simulators can be controlled remotely via an API interface by applying a powerful set of remote commands to control virtually all aspects of the test scenarios including antenna patterns, signal power, signal control, navigation data and by providing vehicle motion in real-time from an external source [11]. This, in turn, enables advanced test cases, like complex, realistic multipath generation calculated in real-time with respect to an external 3-D environment by an external software simulation tool, which then switches on the appropriate multipath and Line of Sight signals by sending remote commands to the RF simulator, as described in [15]. The latest high-end simulator supports complex multi-path rich test cases by providing up to 160 channels in one box [16].

Remote control also allows to inject highly dynamic, real-time, realistic aircraft or spacecraft motion into a GNSS RF simulator Hardware in the loop setup via a flight simulator,e.g. X-Plane. [11], where "the user can emulate a drive or a flight in the lab with a simulator as if flying or driving in the real world. At the same time, this flight or driving simulation controls the vehicle motion of the GNSS simulator. The GNSS simulator then adapts the GPS, GLONASS or Galileo signals accordingly to precisely suit the vehicle motion with high fidelity. The main advantages are the ease of use and the very small time delay between the flight (driving) simulator motion and the RF output of the simulation" [11]. Motion models are available for space, air, land vehicles and sea vessels together with static scenarios and simple motion models in the control software of the RF simulator.

Very high dynamics of air and space vehicles can be represented best with the help of a very high Hardware and software simulation update rate, e.g. 1000 Hz in the GSS9000, resulting in real-time remote control and trajectory delivery with very low latency. Signal accuracy is 0.3 mm RMS for pseudorange, in a range of 120,000 m/sec relative velocity, with a very low phase noise. Signal accuracy and signal quality of simulated signals need to be much better than the performance of the device being tested, else the user measurements do not truly reflect the performance of the device under test, but are degraded by the lacking signal quality [16].

Advanced signal generators are capable of simulating all frequencies and signals from all GNSS and regional systems in the L-bands specified in ICDs, thus enabling true Multi-GNSS tests for research and development [16].

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Examples of simulator test setups relevant for telemetry applications

GNSS system errors:

The above mentioned timing error in January 2016 can be simulated with a full constellation GPS/GLONASS simulator with a special scenario, where the timing parameters in the navigation message are set to reflect a timing offset of -13 µsec in 15 GPS satellites, which represent about half of the visible satellites at each location. In the navigation message, every single parameter and each bit can be modified individually inside the control software SimGEN. Subsequently these changes appear in the simulated RF.

Low orbits of Galileo:

After two Galileo satellites were launched in a too low orbit in August 2014, “ESA asked Spirent to develop a special extended message algorithm in SimGEN to calculate the minimum useable orbit and determine if the SVs had enough fuel to reach those orbits

After rigorous analysis it was determined the orbit could be reached with an acceptable compromise on performance and operational life.” [17]. Thus simulation helped to find a workaround in a difficult situation, where satellites were thought to be unuseable initially [personal communication Stuart Smith].

Jamming Test Setup:

Jamming by Personal Privacy Devices disrupted the operation of a Ground Based Augmentation system at an airport in the US in 2012, when a truck with a jamming device drove by.

Real jamming events can be recreated in the laboratory, by first monitoring the signal environment in the field, for instance with a DETECTOR, and then storing snapshot spectrograms of the interference events. In a third step, these snapshots are converted to test cases, which are simulated by a combination of a GNSS RF simulator and an RF interference generator. The simulator setup consists of a RF GNSS simulator, up to four Vector Signal generators, a combiner unit and the control software SimGEN that controls all the signal sources either in a coherent or a non-coherent way and is adapted to the vehicle motion with relation to the jammer.

Different types of interference can be added: CW, swept CW, stepped CW, pulsed CW, AM, FM, Gaussian Noise and real waveforms, as seen and recorded in the field. Jammer signal power is automatically adapted depending on the distance between the vehicle and the jamming source. Each interference source can operate independently with either fixed or modelled signal power level. The interference generator can be controlled via an interference file, interactively, or via remote commands.

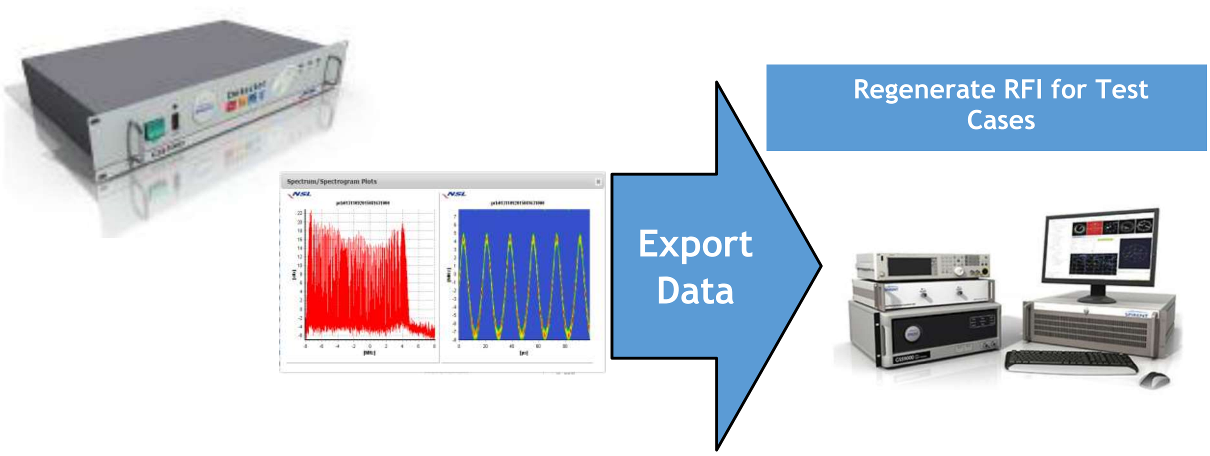

Figure 1 Detector samples jamming snapshots, then they are simulated by an interference simulator

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E-call

There are different emergency call systems for land vehicles, e.g. e-call for the European Union and ERA-GLONASS for the Russian Federation, with the aim that an in-vehicle system calls for help automatically in case of an emergency. ERA-GLONASS is already mandatory, e-call is still under development. The In Vehicle System (IVS) for emergency calls for land vehicles consists of several components, mainly one determining the GPS/GNSS position, and a GSM part transmitting the emergency call including the position data to a public safety answering point (PSAP). The GSM communication with the PSAP needs to be tested in addition to the GPS/GLONASS position fix. A complete test solution for verifying the functionality and conformance of the ERA GLONASS system by Spirent consists of an eCall IVS/PSAP simulator, a GPS/GLONASS positioning simulator and a GSM-wireless network emulator.

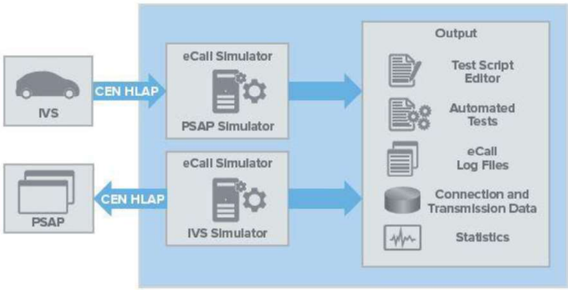

Figure 2 Schematic overview of E-Call Test Setup

This allows testing of the PSAP, the GSM and the GPS/GLONASS simulation, including all officially prescribed test scripts by CEN/ETSI [19].

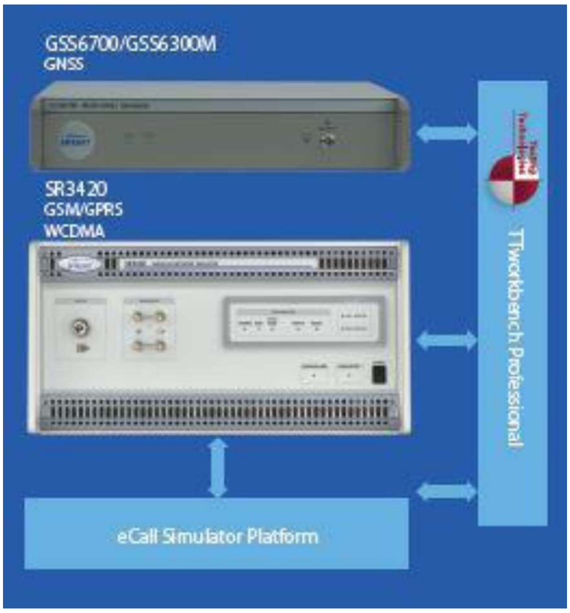

Figure 3 Example of hardware in an E-Call Setup

Accuracy and reliability of Spirent RF signal simulators have been verified in cooperation with major Research Institutions: ESA and DLR [20,21] and have been certified by national authorities of the US, e.g. GPS JPO and GPS Wing and the Russian Federation for GLONASS simulators.

Conclusion:

In this paper, we have shown that the operation of telemetry applications with GPS/GNSS is likely to be compromised by various errors and external events, from time to time. Proper testing is mandatory to improve robustness and continuous, uninterrupted operation.

Simulators allow testing of a wide range of errors, some of which cannot be tested in the field, for example GNSS system errors.

Simulators provide a level of repeatability and control in the lab that are often unattainable in real-world environments. The ability to control test conditions and dynamics repeatedly with ease is extremely effective for system testing and evaluation throughout the system development lifecycle. Using a simulator-based test solution allows fine – tuning and evaluation of navigation algorithms and system performance across a range of operational test scenarios unattainable from field trials [11].

Specialized simulation systems are available for a wide range of applications, covering all major required test cases.

References:

[1] K. Hünerbein,Global Satellite Navigation: new trends, highlights and risks, Conference Proceedings of European Telemetry Conference, Munich, 12th-14th, June, 2012: 370-384.

[2] U. Bestmann, B. von Wulfen, P. Hecker, F. Kneissl, V. Kropp, Aviation Applications: Hybrid Navigation Techniques and Safety-of-Life Requirements Part 2, Inside GNSS, July/August 2010: 62-68.

[3] R. Freeman. Radio System Design for Telecommunication, 2007, 3rd Edition, 524.

[4] K. Hünerbein, Benefits of Multiple GNSS in Aircraft Navigation, Conference Proceedings European Telemetry Conference, Hamburg, 17th-20th May 2010, 361-366.

[5] GPS World, Australia enacts new GNSS requirements for aviation. February 18, 2016, online, http://gpsworld.com/australia-enacts-new-gnss-requirements-for-aviation/

[6] FAA Frequently Asked Questions about ADS-B, online, 2016, https://www.faa.gov/nextgen/programs/adsb/faq/#1

[7] ESA, AIS, 2016, online, http://www.esa.int/Our_Activities/Telecommunications_Integrated_Applications/Satellite_-_Automatic_Identification_System_SAT-AIS

[8] K. Hünerbein, W. Lange, Real Life Evidence for Spoofing and Jamming of GNSS Receivers, Conference Proceedings of CERGAL, 7th-8th July, Darmstadt, Germany, 2015.

[9] A. Rügamer, D. Kowalewski, Jamming and Spoofing of GNSS Signals – An Underestimated Risk?!, 2015, FIG Working Week 2015, From the Wisdom of the Ages to the Challenges of the Modern World, Sofia, Bulgaria, 17-21 May 2015.

[10] Spirent Communications. Fundamentals of GNSS Threats, 2015, White Paper.

[11] K. Hünerbein, W. Lange, User friendly, real time remote control of satellite navigation signal simulation by emulating realistic flight trajectories and driving routes with a standard flight simulator, European Navigation Conference 25th-27th of April 2012, Gdansk, Poland
and European Journal of Navigation, Aug 2012.

[12] N. Fedora, C. Ford, P. Boulton, A Versatile Solution for Testing GPS/Inertial Navigation Systems, Proceedings of the 21st International Technical Meeting of the Satellite Division of The Institute of Navigation, September 16 - 19, 2008, Savannah International Convention Center.

[13] GPS World System News, GLONASS Fumbles forward: Two April Disruptions Furnish Fodder for Multi-GNSS Receivers and Alternative PNT, 2014, GPS World May 2014, 16,17.

[14] GPS World: System of System, Microseconds go Missing in GPS Ground Control Glitch. GPS World March 2016, 12.

[15] K. Hünerbein, G. Moura. A new tool for simulation of geospecific multipath and obscuration of GPS/GNSS signals with relation to realistic 3 D city models, 2014, Conference Proceedings of the European Telemetry Conference, Nürnberg, 3rd-5th June, 2014.

[16] Spirent Communications, Datasheet for GSS9000, 2014

[17] Stuart Smith, Constellation status of GNSS, 2015, Spirent internal presentation.

[18] DLR, Orthorectification, online, http://www.dlr.de/eoc/en/desktopdefault.aspx/tabid-6144/10056_read-20918/

[19] Spirent Communications, Spirent eCall/ERA-GLONASS IVS Test Solution, 2015, Datasheet

[20] P Boulton, R Wong, A Read, Galileo RF Constellation Simulator Design Verification and Testing, 2007, Conference Proceedings of Frequency Control Symposium joint with the European Frequency and Time Forum, Geneva, 29th May – 1st June 2007, 511-516.

[21] A Hornbostel et al, “Simulation of Multi-Element Antenna Systems for Navigation Applications”, IEEE Systems Journal, March 2008, Vol. 2, No. 1, pp. 7-19