Performance Evaluation of the Multi-Constellation and Multi-Frequency GNSS RF Navigation Constellation Simulator NavX®-NCS

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BIOGRAPHY

Dr. Günter Heinrichs received a Dipl.-Ing. degree in Communications Engineering from the University of Applied Science Aachen in 1988, a Dipl.-Ing. degree in Data Processing Engineering and a Dr.-Ing. degree in Electrical Engineering from the University Paderborn in 1991 and 1995, respectively. In 1996 he joined the Satellite Navigation department of MAN Technologie AG in Augsburg, Germany, where he was responsible for system architectures and design, and digital signal and data processing of satellite navigation receiver systems. From 1999 to April 2002 he has served as the head and R&D manager of MAN Technologie’s satellite navigation department. In May 2002 he joined IFEN GmbH, Poing, Germany, where he was the head of business development and R&D management. Since March 2008, he is also the head of the “Customer Applications” department of IFEN GmbH, responsible for all customer, marketing and sales related activities.

Markus Irsigler received his diploma in Geodesy and Geomatics from the University of Stuttgart, Germany. In the year 2000, he joined the Institute of Geodesy and Navigation at the University of the Federal Armed Forces Munich where he worked as a research associate. At the beginning of 2007, he joined IFEN GmbH, where he currently works as NCS product manager and system engineer.

Dr. Robert Wolf holds a degree in Aerospace Engineering from the Technical University of Munich and a Dr.-Ing. from University FAF Munich. He joined IFEN GmbH in 1999. From 2001 – 2007 he was head of integrity systems department at IFEN GmbH. Since 2008 he is the head of Navigation Products Department, responsible for NCS development.

Dr. Günter Prokoph studied electrical engineering in Erlangen. From 1982-1986 he worked as a research associate at the Institute for High Frequency Technology at the University Erlangen Nuremberg from where he received a Ph. D. (Dr.-Ing.) degree for his thesis on ultrasonic imaging. In 1991 he joined Work Microwave GmbH. Since 1992 he is the technical director of the company.

INTRODUCTION

NavX®-NCS is the first product in a new generation of combined Galileo/GPS products from IFEN GmbH. Whether for mass market application, using combined GPS/Galileo signals on E1/L1, or safety of life signals on E1/L1 and E5b/L5 up to high-precision applications with four frequencies simultaneously for RTK surveying, NavX®-NCS masters them all. NavX®-NCS is the first complete Galileo/GPS laboratory test equipment which redefines the frontier of RF navigation constellation simulator technology.

Key drivers for the design were flexibility, scalability and low cost. The simulator consists of three sections: The steering software, which runs on a normal Windows or Linux based PC, the digital base-band part and three or four digital-to-analog up-converter sections.

NAVX®-NCS SYSTEM OVERVIEW

One system – but the full flexibility for the user to configure the NavX®-NCS according to needs puts this innovative RF constellation simulator at the leading edge of navigation signal generator technology.

Whether for mass market application, using combined GPS/Galileo signals on L1/ E1, or safety of life signals on L1/E1 and L5/ E5b up to high-precision applications with four frequencies simultaneously for RTK surveying, NavX®-NCS masters them all.

Key features. The NavX®-NCS is a multi-channel, multi-frequency GNSS RF constellation simulator capable of simulating combined GPS/Galileo/SBAS signals. It provides reliable and repeatable generation of all relevant GNSS signals (GPS L1/L2/L5 and Galileo E1/E6/E5ab) out of one single chassis. The NavX®-NCS chassis features a 19” rack mounting option allowing easy integration into standard laboratory equipment and a very compact design (maximum of two height units only!).

Figure 1: NavX®-NCS signal generating unit / control PC.
Core of the signal generating unit are the RF modules, each of them featuring 12 channels. One NavX®-NCS chassis can be equipped with up to 9 RF modules, so that a maximum number of 108 channels per chassis are available. Each RF module is fully configurable in terms of frequency and signal modulation (frequencies can be individually assigned to any RF module). Together with the large amount of available channels, this architecture ensures full flexibility for a variety of test applications.

**Interfaces and Hardware Upgrade Options.** NavX®-NCS devices feature various input and output interfaces like Ethernet connection, an input for external reference oscillators, 1 PPS, a hardware trigger input or an output for the internal clock signal. In addition to the standard RF output at the front of the NavX®-NCS, an additional monitoring port is available at the rear panel. These input and output interfaces offer the potential to integrate the NavX®-NCS to other hardware or to integrate it into existing test environments.

NavX®-NCS systems are delivered with a control PC, which is used for simulation configuration and interactive control (see section “NavX®-NCS Software”). The control PC is basically an external one. However, depending on the desired NavX®-NCS product variant, an embedded PC can be selected instead of an external one. Further upgrade and configuration options comprise the implementation of additional RF modules or RF outputs, or the implementation of an internal noise generator.

**Product variants.** The customers can select among two different NavX®-NCS product variants, namely

- NavX®-NCS Standard and
- NavX®-NCS Professional.

The “NavX®-NCS Standard” device is a single-frequency constellation simulator covering GPS/Galileo and SBAS signals on L1/E1. It supports a maximum of 24 channels. Since the “NavX®-NCS Standard” is fully compatible with the testing requirements specified in the current 2G and 3G mobile phone standards, it is suited to set up an integrated single-frequency, multi-constellation test environment for GNSS receiver production testing. It comes in a single height unit chassis.

The “NavX®-NCS Professional” is a multi-frequency constellation simulator covering GPS/Galileo and SBAS signals on L1/E1, L2, E6, and L5/E5ab. It supports a maximum of 108 channels and a multitude of hardware and software upgrade options. Due to the large amount of supported hardware channels and GNSS signals, it is ideally suited to set up an integrated multi-frequency, multi-constellation test environment for GNSS receiver development and testing. It comes in a two height unit chassis.

**NAVX®-NCS HARDWARE.**

The RF hardware is the core of the NavX®-NCS. Through its innovative RF module design, the RF frequency of each module can be changed by configuration. Per RF chain on one RF module, up to twelve channels can be simulated. By combining 6 RF module in one NavX®-NavX®-NCS hardware chassis a constellation simulation of 12 GPS (L1, L2, L5) and 12 Galileo (E1, E6, E5ab) simultaneously can be achieved ‘out-of-the-box’!

All simulation parameters are highly configurable. The software also provides the hardware with raw navigation data frames, including time-stamp. The base-band processor receives the data and constructs the base-band signal modulated with the data frames. Separate Doppler offsets for code and carrier as well as code offsets are also applied at this stage. The base-band signals for each frequency band are combined digitally and up-converted using one analogue chain. This approach practically eliminates all relative group-delays within each band.

The up-converter shifts the combined digital signal to the appropriate RF-frequency. Each up-converter can be configured independently to any RF-frequency in L-band being a multiple of 5.115 MHz and can service up to 12 satellites (Galileo and/or GPS). Figure 3 shows an open NavX®-NCS with three RF modules, 10 MHz reference module, power supply, internal reference oscillator section and Ethernet.

**Figure 2: Overview of the NavX®-NCS concept.**

**Figure 3: NavX®-NCS Hardware Insight**
The channel concept of a NavX®-NCS module is extremely flexible and supports all relevant modulation schemes (BSPK, QPSK, Tri-Phase Interplex, ALT-BOC). Each channel can be freely configured in terms of chip rate, PRN codes, data rate etc. The codes are defined in terms of “memory codes”, i.e. user-defined codes can easily be included.

The NavX-NCS can be synchronized to an external timing and frequency reference (1PPS and 10 MHz sine wave), thus providing the capability to integrate it into a test environment.

NAVX®-NCS SOFTWARE

The NavX®-NCS is configured and controlled by the “NavX®-NCS Control Center”, a flexible and powerful software which allows intuitive simulation configuration and interactive control. It provides access to all important simulation parameters and features all logging, monitoring and visualization options necessary to evaluate and analyze each simulation run. Figure 4 illustrates the general appearance of the graphical user interface of the “NavX®-NCS Control Center” software.

The software runs either on an external PC (standard delivery for NavX®-NCS Standard and Professional devices) or on an embedded one (optional for NavX®-NCS Standard devices). The embedded PC is integrated into the signal generating unit and peripheral devices such as monitors or keyboards can be directly connected to the NavX®-NCS device.

Software Features

In conjunction with the “NavX®-NCS Professional” device, the NavX®-NCS Control Center software supports the generation of GPS and/or Galileo simulations (at all relevant frequency bands), the incorporation of satellite-based augmentation systems like EGNOS, WAAS, MSAS or QZSS and the generation of assisted GNSS data. The software supports definition and simulation of user trajectories, so that either static or dynamic simulations can be performed. In addition to select from a pool of pre-configured simulations, the user can configure its own simulation by adjusting the relevant simulation parameters. Some important simulation configuration options are described in the following paragraphs.

Figure 4: Graphical user interface of the “NavX®-NCS Control Center” software.

Space Segment. Basic features for the definition of satellite orbits are the capability of importing precise ephemeris or almanac data (e.g. SP3 or YUMA) or the definition of orbit parameters per satellite (including orbit perturbations). Entire satellite constellations can be generated by using the “Single-Step Constellation Generation” function. One important feature is the capability to generate combined GPS/Galileo/SBAS constellations. Figure 5 illustrates such a combined constellation using three orbit planes for Galileo and six for GPS. In addition, two geostationary satellites were incorporated into the constellation.

Other simulation configuration options related to the space segment are the definition of satellite clock errors or satellite antenna patterns.
Signal Propagation and User Environment. Modeling signal propagation characteristics basically comprises the definition of tropospheric and ionospheric properties as well as the definition of a multipath environment. Besides the capability of defining simple multipath conditions like the presence of ground multipath, the NavX®-NCS Control Center software can be upgraded with an “Advanced Multipath Simulation” extension (see section on software versions and extensions). Other simulation configuration options related to the user environment include the definition of user antenna patterns or the use of arbitrary elevation masks (as illustrated in Figure 5).

All NavX®-NCS systems support the simulation of user trajectories. User trajectories can either be selected from the available trajectory data base (pre-installed trajectories, see Figure 6) or defined by using an internal trajectory editor. Alternatively, externally recorded GPS tracks can be imported into the “NavX®-NCS Control Center” and can be “replayed”. Various data formats like NMEA or GPX are supported.

Software Versions and Extensions

Software Versions. As it is the case for the NavX®-NCS hardware, where a Standard and Professional version is available, the NavX®-NCS Control Center software also reflects this distinction. With respect to appearance, handling and basic functionality, both software versions (called “NavX®-NCS Control Center Standard” and “NavX®-NCS Control Center Professional”) are basically the same. However, compared to the “Professional” full-featured version, the “Standard” version has limited functionality and fewer upgrade potentials. The full upgrade potential is restricted to the “Professional” version, for which various software extensions are available.

<table>
<thead>
<tr>
<th>Optional SW Extensions</th>
<th>Standard</th>
<th>Professional</th>
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<tbody>
<tr>
<td>Advanced Multipath Simulation</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Advanced Trajectory Simulation</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Assisted GNSS capability</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>EGNOS/WAAS/MSAS extension</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>QZSS capability</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Differential GNSS capability</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Attitude capability</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 1: Available software extensions for the NavX®-NCS Control Center software.

Performance Results

The following figures show the receiver estimated versus NCS simulated position.
clude receiver errors as well, the power levels have been adjusted to keep the C/N0 around 48 dBHz to minimize that influence. The performance figure obtained in the static case shows the excellent performance of the NCS.

The numerical results in positioning accuracy are impressive:

- Maximum deviation from simulated position:
  - East: 0.04 m
  - North: 0.06 m
  - Up: 0.24 m

- Standard deviations:
  - East: 0.01 m
  - North: 0.02 m
  - Up: 0.04 m

The next figure shows a combined metric obtained using a dynamic user trajectory. The trajectory used has a serpentine shape as shown to the right.

Again performance is excellent, confirmed by numerical evaluation:

- Maximum deviation: 0.25 m
- Standard deviation: 0.03 m

CONCLUSIONS

The NavX-NCS is a flexible multi-constellation and multi-frequency signal generator showing outstanding performance. It is an ideal platform supporting GNSS receiver developments being a highly controllable reference to test your receiver against.

ACKNOWLEDGEMENTS

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