Monitoring Station for GNSS and SBAS

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BIOGRAPHY

Pavel Kovář received M.Sc. degree (1992) and Ph.D. (1996) degree in electrical engineering at the Czech Technical University (CTU) in Prague. He worked as a senior design engineer in communications company Mesit Uherske Hradiste and now he is working on his associated professor degree. He is involved in the design of advanced GNSS signal processing algorithms and its implementation into software receiver architecture.

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Libor Seidl received M.Sc. degree (1990) and Ph.D. degree (2000) in electrical engineering - radioelectronics at the CTU in Prague. He works as assistant professor in CTU and now he is working on his associated professor degree. He is specialized in GNSS receivers design (GPS, GLONASS, Galileo), GNSS intersystem integration, augmentation and differential GPS techniques.

Pavel Puričer received M.Sc. degree in electrical engineering in 1996 at the CTU in Prague. He works as assistant professor in CTU in area of GNSS signals processing. He is involved in the use of augmentation data for GNSS in difficult environment.

INTRODUCTION

The paper deals with the reception, processing, statistical evaluation and archiving of EGNOS (European Geostationary Navigation Overlay Service) signals together with data of present and future GNSS (GPS, GLONASS, and Galileo). EGNOS, Satellite Based Augmentation System (SBAS), provides integrity and ranging information as a complementary data to the systems GPS and GLONASS. The SBAS data are used for performance and reliability enhancement of current GNSS systems. Such service is crucial for safety of life applications, therefore from their point of view it is necessary to provide monitoring of EGNOS itself as well. The requirements on transparency and capability of the post processing of system data for investigation of the non standard system and receiver states have to be taken into account in design of the data format and communication protocol for such monitoring station.

The EGNOS monitoring station, described in the paper, is a part of GNSS monitoring station at the Department of Radio Engineering, Faculty of Electrical Engineering of the Czech Technical University in Prague. This GNSS monitoring station has long experience in the monitoring GPS and GLONASS systems and archiving their data for post processing purposes.

One of the experimental receivers developed at the Department of Radio Engineering was at present dedicated to the EGNOS monitoring service. This receiver is based on the Software Defined Radio concept, using FPGA equipped with two processor cores as a signal processing software carrier. The same concept is used for other receiver that is prepared for simultaneous reception of GPS, EGNOS, and Galileo signals. The current and future status of GNSS monitoring station configuration is presented in the paper.

The EGNOS signals are processed by receiver software together with received GPS signals and then measured data for both systems are provided for statistical analysis and storage. GPS and EGNOS low level measured data are stored in the proprietary format consisting for example samples of the complex envelope of the receiver's correlators and detailed information of the receiver status. Besides that, the provided data are converted to the RINEX format and archived as well. The RINEX formatted data can be statistically processed for example by PEGASUS software provided by Eurocontrol. Besides that possibility, the low level data are evaluated by Matlab scripts for more detailed analysis. Such "raw" data archiving can serve for example for analysis of uncertainties and problems of EGNOS signal or for use of those data for offline simulations. The paper present examples of output data from GNSS monitoring station realization.

The archived data and statistics results are planned to be available to the public through Internet.

GNSS AND SBAS MONITORING

The satellite navigation systems monitoring has long tradition at our department. We continuously monitor GPS and GLONASS systems signals since 1996 and also share data from this monitoring via internet. Now we extend the monitoring to new systems EGNOS and Galileo.

The EGNOS is the first step on the way to European satellite navigation system Galileo. It is a kind of Satellite-Based Augmentation System covering Europe. Geostationary satellites broadcast a GPS-like ranging signal with embedded corrections, providing improved accuracy, availability and integrity over GPS and GLONASS. The EGNOS enable use of these two systems for safety critical applications. Primary purpose of EGNOS, which has been developed for, is to support position determination and navigation of civilian aircrafts.

The Galileo is an European navigation satellite system which is currently under development. In its full operational status it will provide wide spectrum of services from basic Open Service (OS) to Safety of Life service (SoL) and Public Regulated Service (PRS). The Galileo navigation system shall be fully interoperable with existing GNSS systems.

In the last years our team has been building the experimental GNSS receiver based on software defined radio architecture. Current second generation receiver consists of a compact RF front-end and a digital processor based on programmable logic FPGA Virtex-II Pro by Xilinx with integrated PowerPC processor cores. The software receiver is suitable for experiments with signal processing and further allows more detailed access to the signals of satellite navigation systems.

Monitoring station with experimental GNSS receiver provides more information about signals GPS system and recently added EGNOS system. Monitoring station is also capable to receive signals of constructed European navigation system Galileo [1]. The Galileo system and modernized GPS are coming with new services for safety-of-life applications.
The development of the GNSS systems and introduction of the new guaranteed services performance requires the development of the GNSS monitoring system. The basic requirements on the provider-independent monitoring system are [2]:

- Measurement and storage of signal or data at very low level to be able to reconstruct the anomalous behavior of the navigation system and simultaneously eliminate mistakes in the monitoring system.
- Support of the investigation of the navigation system anomalous status and secure data for reconstruction of the anomalous behavior of the navigation receiver.
- Support of the low level data and signal transformations to the widely used format for other analyses.
- Sharing capability of monitoring data via internet.

This requirement respects designed GNSS monitoring station architecture. The construction of the GNSS monitoring station was planned in several phases. The monitoring station is now in the first phase and provides monitoring all in view GPS, EGNOS, and Galileo satellites on L1 frequency. In the next phase the capability of monitoring of the Galileo E5, GPS L2 CA, and GPS L5 signals will be progressively implemented.

EXPERIMENTAL RECEIVER PARAMETERS

The simplified block diagram of the second generation experimental GNSS receiver is a part of the Fig. 1 (with one RF channel only). This receiver consists of three main parts: radiofrequency units (up to four independent RF channels), analog to digital converters (ADC), and DSP unit with FPGA Virtex-II Pro with integrated PowerPC processor cores. This new generation of programmable chip enables to integrate whole high performance embedded computer and signal processing to the single chip.

The receiver is based on super-heterodyne concept with single conversion and standard intermediate frequency 140 MHz. Radio frequency unit of the experimental GNSS receiver consists of up to four independent radio channels. Every independent RF channel of receiver is realized by front-end unit branch module. Front-end unit branch modules differ only by used input filter (according to the frequency band of processed signals), otherwise are identical. Front-end can operate at selected frequency in range 1– 2 GHz, and provides amplification of signal and sufficient frequency selectivity. Each channel of the receiver can process signal from individual antenna. It is also possible to use one antenna for two or more channels together.

The bandwidth of each channel is 24 MHz according to SAW filter at intermediated frequency. The bandwidth of the signal can be also reduced by digital filter in receiver DSP, if necessary. A specialized synthesizer is used as a local oscillator, it is hybrid integrated circuit combining phase lock loop and voltage controlled oscillator. Frequency standard

10 MHz for synthesizer is provided by local oscillator on ADC board. The synthesizer can be driven from external frequency source as well.

The level of signal coming from antenna can vary because of presence of interfering signals or due to thermal noise variance. The common GNSS receivers usually use A/D conversion with one bit quantization that is not sensitive to level variances. The A/D conversion in experimental GNSS receiver uses 8-bit quantization. That's why it is necessary to keep constant signal level at the input of A/D converters. This requirement is realized by gain control block inserted at the end of RF unit branch module. The gain of the receiver can be controlled by AGC (Automatic Gain Control) loop in 40 dB range.

The ADC part is also used as frequency reference unit for RF part synthesizers. The main features of this part are:

- 8 bit ADC converters 4x,
- sampling frequency 80 MHz,
- reference frequency 10 MHz,
- stability 0.3 ppm,
- optional external reference input,
- reference outputs 4x.

The signal processing programmed into the FPGA ensures transformation of the intermediated frequency signal to the base band and correlation reception algorithms. These algorithms have low complexity, but they require high numerical power. Typical example can be a correlator block. The remaining high complexity but less numerical demanding algorithms are executed in PowerPC processor core e.g. PVT (Position, Velocity, and Time) algorithm.
The Virtex-II Pro prototyping board has been used to reduce technological demands for FPGA board development and construction. The receiver is equipped with switched power supplies and high precision frequency reference with stability 0.03 ppm. The complete receiver is mounted into the 19-inch case.

MONITORING STATION ARCHITECTURE

Monitoring station consists of the second generation experimental GNSS receiver connected to the PC workstation and disk station (Fig. 1). For this purpose the 16 identical GPS/EGNOS/Galileo correlators capable to process BPSK and BOC(1,1) modulation were programmed to the receiver FPGA. The PRN code is stored in the correlator 16 Kbits RAM memory and can be downloaded from the receiver computer. GNSS receiver was equipped with the L1 front-end.

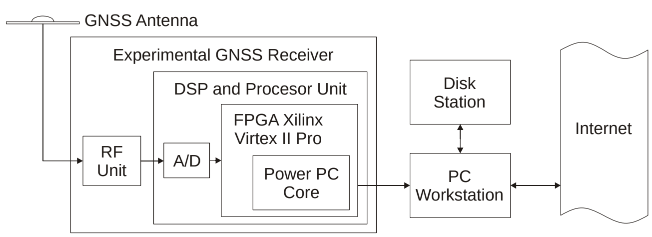

Fig. 1. GNSS monitoring station architecture.

The requirements on transparency and capability of the post processing investigation of the non standard system and receiver states were taken in account during design of the data format and communication protocol for GNSS monitoring station. From this reason the monitored data are stored in PC workstation in raw form to keep available all information for measurement analyses and elimination of the errors in the monitoring station. Monitoring station raw data content:

- raw carrier phase measurement,
- extended PLL status
  - actual tracking error,
  - detailed PLL status indicators,
- raw code measurement,
- extended DLL status
  - actual tracking error,
  - signal to noise ratio,
  - detailed DLL status indicators,
- IQ signal samples wide one bit
  - 20 ms for GPS
  - 2 ms for EGNOS,
  - 1 ms for Galileo.

Further on the attached PC workstation runs software for analyses of the stored data and software for transformation of this raw data to the "Receiver Independent Exchange Format" (RINEX). The PC workstation also provides this data via internet.

DATA ANALYZING

For analyses of the RINEX data can be used navigation and surveillance software package PEGASUS (Prototype EGNOS Analysis System Using SAPPHIRE) by Eurocontrol. The PEGASUS software is a tool which allows analysis of collected data (Fig. 2).

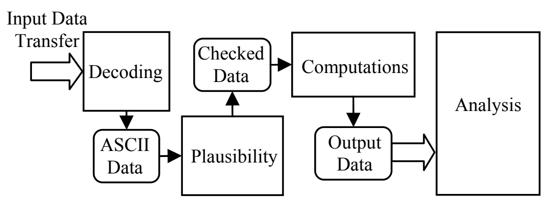

Fig. 2. PEGASUS data processing structure [3].

The tool analyzes raw GNSS and SBAS data streams using only algorithms contained in the published standards and giving the possibility of easy access to the data processing with graphical presentation of the results (some examples on Fig. 3 to Fig. 5).

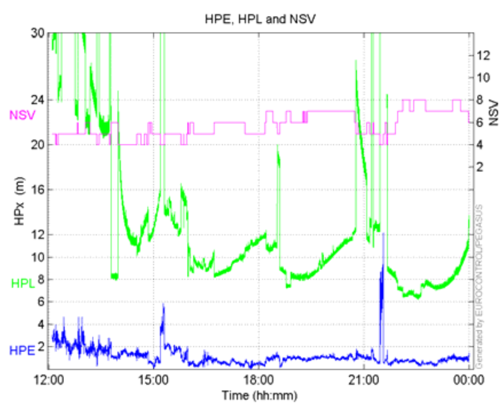

Fig. 3. Horizontal position error, horizontal protection limit (HPL), and number of satellites in view (NSV).

Stanford plot shows the absolute value of the position error (true error in navigation solution with respect to the surveyed antenna location) versus the protection level (computed for each and every navigation solution) for the horizontal (Fig. 4) and vertical (Fig. 5) components, where the color coding indicates the number of measurement samples. These histograms are used for the evaluation of integrity in the position domain.

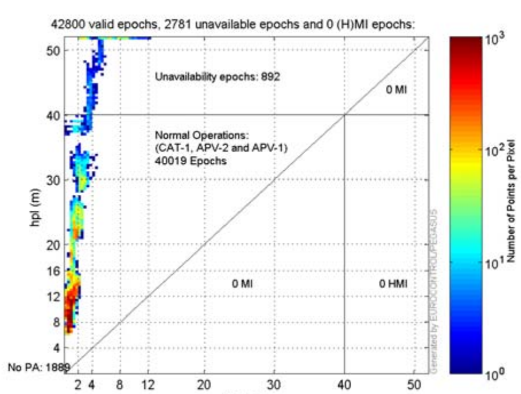

Fig. 4. Horizontal Stanford plot.

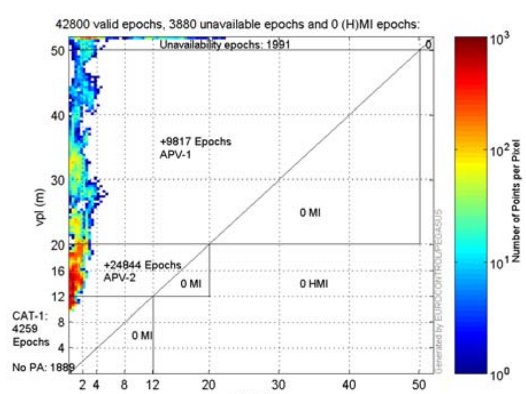

Fig. 5. Vertical Stanford plot.

The other possible way how to analyze the monitored data is to develop special software. This software targeted for Matlab environment is under development. The software will directly process raw data measurement, because RINEX format supports only subset of the raw measurement information. In this time the program performs only basic data checking. Program saves results in to text file with warnings in case of any anomaly caused by receiver or system failure. User is able to display some graphic results of selected data (Fig. 6 and 7).

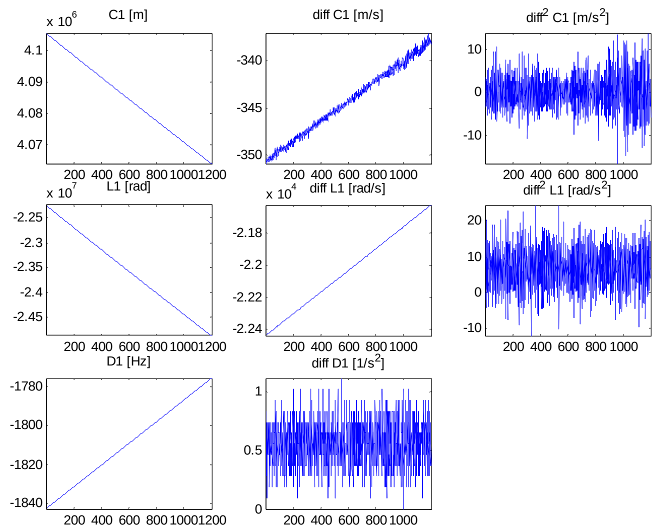

Fig. 6. Raw code measurement, carrier phase measurement, and Doppler shift - simple analysis of signal without failure.

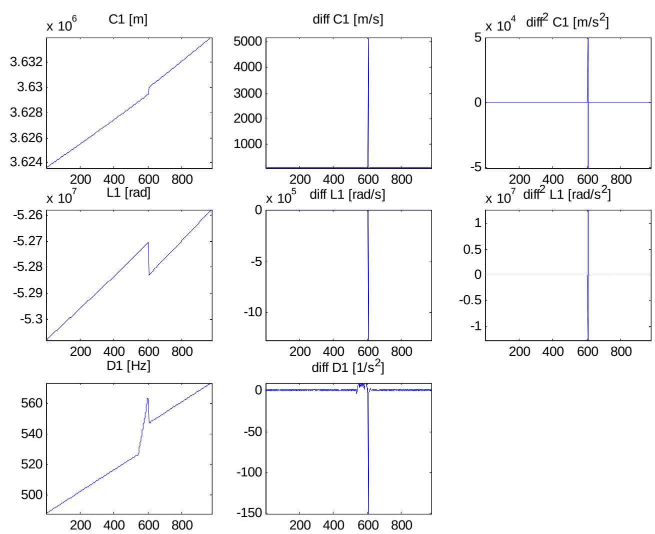

Fig. 7. Raw code measurement, carrier phase measurement, and doppler shift - simple analysis of signal with discontinuity.

On the Fig. 8 is example of displayed complex envelope samples characteristics. It is a sample of receiver correlator output where one sample matches one bit of navigation message. If receiver works well and signal is without anomalies we can see evident BPSK modulation constellation in the presence of noise.

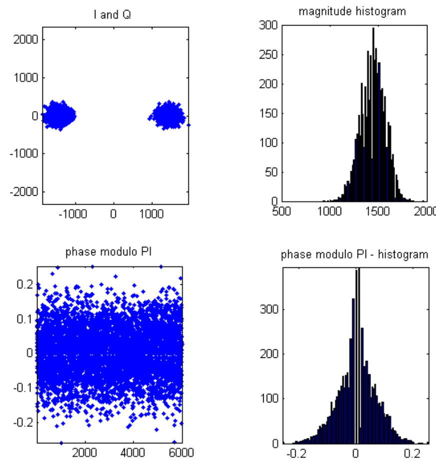

Fig. 8. Complex envelope samples analysis.

CONCLUSION

One of the main advantages of use an experimental software receiver for monitoring of GNSS is its possibility of access to the GNSS signal at the lowest level to process and examine raw data in comparison with the possibilities offered by classical commercial receivers. Moreover, the signal processing of such versatile design can be modified according to the character of monitoring to provide information in the most appropriate and utilizable form.

In the frame of this project we plan to upgrade GNSS monitoring station to all Galileo frequencies. The second version of the experimental GNSS receiver has not sufficient performance of the FPGA for implementation of the approximately 100 correlators including Galileo E5 correlators, which should process extra wideband signals. Our plan therefore supposes the design of the third version of the experimental GNSS receiver based on latest Virtex 4 FPGA by Xilinx with higher performance. The goal of this receiver is sufficient power for processing of all Galileo signals in space.

ACKNOWLEDGEMENTS

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