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Raw GNSS data grabbing and software receivers: a solution to make an Ionospheric Scintillation Monitoring Receiver a multifold analysis platform

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ABSTRACT

The use of Global Navigation Satellite Systems (GNSS) is becoming very popular, and the positioning service that they provide is becoming the basis of several services widely used everyday, not only for positioning purposes. Due to the wide coverage of such systems, their signals can be used as probing signals to retrieve useful parameters to charactherize the atmosphere. In fact the signals while propagating through the Earth's upper atmosphere are affected by severe propagation nuisances, such as phase shifts, group delays and amplitude variations, so that propagation of the GNSS signals through the ionosphere is indeed the most severe and variable cause of errors in GNSS} positioning [1].
At high latitudes, this effect could be even more harmful, because the polar ionosphere is often hit by solar energetic particles driven by the cusps of the geomagnetic field. The use of GNSS signals as probes for ionosphere monitoring is widely used for ionospheric tomography by using GNSS receivers designed to be robust to sever propagation conditions, and providing as outputs specific indexes derived from the observation of the received signals. The clear advantage of GNSS-based ionosphere monitoring is that the GNSS signals are available at no cost, and by using GNSS receivers avoid the installation of other large and expensive equipments such as ionosondes and other ad hoc monitoring equipments.

Professional and commercial hardware GNSS receivers have been successfully exploited for ionosphere monitoring since years for the extraction of the Total Electron Content (TEC) and ionospheric scintillation phenomena detection. In particular, Ionospheric Scintillation Monitoring Receivers (ISMRs) are commercial devices specifically designed for monitoring such ionospheric events affecting GNSS signals. Despite of this consolidated approach, recent trends in GNSS receivers implementation also consider Software Defined Radio (SDR) as a valuable technology.

SDR refers to an ensemble of hardware and software technologies and design choices that enable reconfigurable radio communication architectures. According to such an approach functional blocks of the receiving chain which are normally hardware implemented, are realized as software modules, either on programmable platforms (high-performance general purpose

processors) or on reconfigurable hardware, such as Field Programmable Gate Arrays (FPGAs), Digital Signal Processors, microprocessors or ASIPs.

Implementation of GNSS receivers according to the SDR approach, allows to access intermediate and low level signal processing stages, having full control of the receiver architecture and offering to the user a larger subset of observables. When the GNSS receiver is used for monitoring purposes, the software implementation yields higher flexibility and re-configurability and, in turn, enables the possibility to design and implement innovative ionosphere monitoring techniques.

1. The software radio approach to Scintillations monitoring

The most common architecture of a GNSS SDR receiver can be split in two blocks, as represented in Figure 1:

- A GNSS antenna and a Radio Frequency (RF) front-end, which acts as a data grabber; the GNSS signal is received, pre-conditioned, analog-to-digital converted, and finally raw GNSS samples are stored on mass memories for further processing .
- A signal processing stage, which can process the stored data, either in real time or in a post-processing phase. This is the actual stage of the receiver which is SDR implemented.

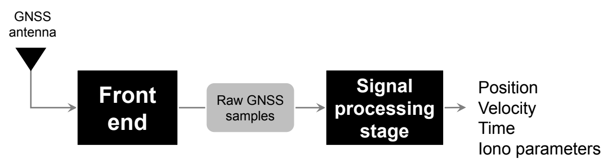


Figure 1: GNSS receiver architecture.

The implementation by means of the SDR approach adds flexibility to the implementation of the whole monitoring station. In fact, when using commercial GNSS receivers, only the storage of post-processed data is possible, such as ionospheric data and outputs of the correlation stages.

By means of the SDR implementation, the two different blocks can operate independently during monitoring operations. Raw signal samples collected on site can be transferred exploiting external memories and then post-processed, either by using different configurations and architectures of the receivers (e.g. loops bandwidth or order), or by implementing techniques and innovative algorithms tailored to ionosphere monitoring.

This feature makes the approach equivalent to a plethora of receivers, the performance of which can be replicated changing the configuration of the software architecture.

Even considering the hardware cost for the front-end section, the solution is cost effective, especially when considering the possibility to mimic the behavior of different receiver architectures and the possibility to replay scenarios for significant atmospheric events by means of advanced signal processing algorithms (for example for multipath and interference removal).

It is then clear that any hardware receiver, cannot provide such a wide range of options for the processing, and the user has limited possibility to configure the receiver, and only the post-correlation I and Q data are available.

This approach is valuable if the core structures of the data collection system do not mask or modify the features of the collected signals, assuring that the information on ionospheric phenomena is preserved. The receiver, as well, has to grant the quality of the monitoring at least at the level of what is considered today state-of-the-art.

Storage of raw samples, however, is not an easy task, since it requires large storage capabilities and/or large bandwidth data connections, which are in general, precious resources. Furthermore in most of the case scintillations monitoring is interesting at equatorial regions and/or polar regions, and it takes place, as a matter of fact, in lands where such resources either are not available or are difficult to be deployed.

As far as the front-end is concerned, two are the main parameters affecting the fidelity of the recordet signal to the physical one: The sampling frequency and the number of quantization bits used for the digital representation of the signal (See Figure 2).

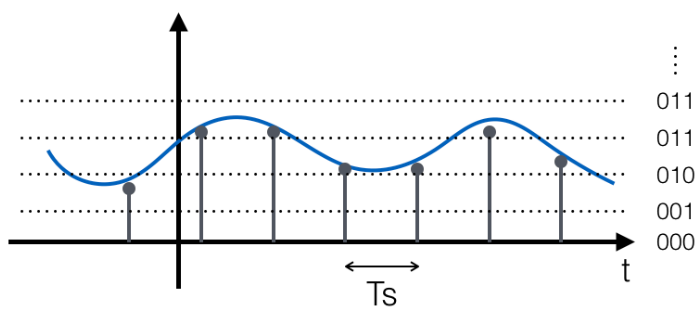


Figure 2: The sampling and quantization process.

Table 1. Parameters of the front-end configuration.

Sampling frequency	5 MHz
Intermediate frequency	0 Hz (baseband)
Sampling type	I and Q sampling
Quantization	16 bits

As an example, with the configuration parameters in Table 1, used for the data-grabber based on the use by two Universal Software Radio Peripheral (USRP) N210 devices, for acquiring L1 and L2 bandwidths respectively, 30 minutes of double frequency raw data amount to about 80 GB.

Continuous monitoring and storage of the raw samples, is then not possible since it would require a quite huge use of storage resources, which cannot normally be afforded.

Reducing the number of quantization bits, the total size of the files would be reduced. However, one of the main advantages of storing the raw samples is the possibility to re-play the event and process the data with different configuration of the software receiver. A strong limitation of the number of quantization levels (i.e. of the number of bits necessary for their representation) limits the fidelity of the re-played scenario, sometimes introducing artifacts in the results.

A proper automatic policy for storage of the raw samples of the signal has then to be defined.
It is well known that while in equatorial regions scintillations events are commonly observed during post-sunset hours, in polar regions there is no direct dependency with the position of the sun, and as a consequence at a specific time of the day when scintillations would be more likely to occur [2][3]. Therefore, it is not possible to reduce the data collection to a few post-sunset hours, as it is often done at equatorial latitudes [4][5], but it is necessary to set-up a continuous monitoring over time. The solution adopted and implemented in the data acquisition system is to implement a basic software receiver able to automatically grab a chunk of raw data, quickly process them, computing scintillation indices for the GPS L1 signals. Afterwards, by comparing the results to predefined thresholds of scintillation activity, raw data are either automatically discarded or stored on an external hard drive.

A second problem is related to the data transfer. The bandwidth resources available in any Antarctica research station do not allow transferring such amounts of data. The data can only be moved physically transferring the hard drives on which they are stored. The raw GNSS data will be then available for post-processing only at the end of the campaign, when the system will be disassembled and the hard drives physically shipped back, or taking advantage of material that can be transferred along the year from the Antarctic bases. Nevertheless, by exploiting a slow remote network connection, it will be possible to run the software receiver on selected raw data directly on the computer of the monitoring station, and then to transfer only the results in a compact format which can cope with the limited bandwidth available.

2. The case-study of the DemoGRAPE project

The effectiveness of the architecture has been proved in several installations at equatorial regions, and lately by the installation of two data collection systems designed and realized for the purposes of the DemoGRAPE project [6] in two Antarctica research stations: the Brazilian station Estação Antártica Comandante Ferraz (EACF), and the South African Antarctic base SANAE IV. The two monitoring stations were installed within the XXXI Italian Expedition in Antarctica of the Italian National Research Program (Programma Nazionale di Ricerche in Antartide, PNRA), with the cooperation of the Brasilian National Institute for Space Research (INPE). And of the South African Space Agency (SANSA).
The full station set-up includes three independent monitoring receivers:

- a Septentrio PolaRxS PRO ISMR, providing scintillation and TEC measurements, together with common GNSS observables stored in rinex files;

- GNSS data acquisition system and a software monitoring receiver, specifically developed by the NavSAS group at Politecnico di Torino for ionosphere monitoring over polar regions and described in the following sections.
- 4tuNe, a Galileo/GPS quad-band automatic bit grabber and *ionospheric scintillation monitoring station*, developed by the Joint Research Centre (JRC) of the European Commission [7].

A block scheme of the full set-up is reported in Figure 3.

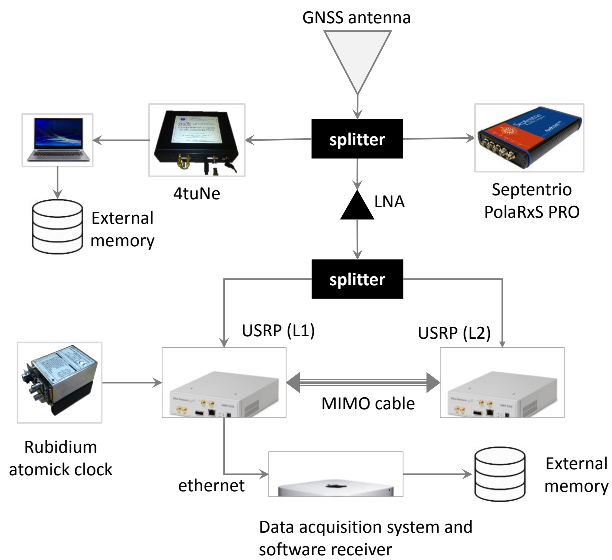


Figure 3. Block scheme of the DemoGRAPE monitoring station installed in Antarctica.

The receivers all share the same antenna: a Septentrio ChokeRing Multi Constellation GNSS Antenna, installed on the roof of the EACF station main module

During the first months of operation, significant events have been observed, and the software processing has been able to provide values for the scintillation indexes S4 and phi60 with the quality of a Septentrio PolaRxS PRO ISMR, as shown in Figure 4 for the phi60 index during a quiet day. Such results have been obtained re-playing the data collected by means of the USRP data grabber (see the parameters of Table 1), and processing the results with a fully software receiver which is able to reproduce a receiver architecture very similar to the one implemented in the PolaRxS PRO ISMR.

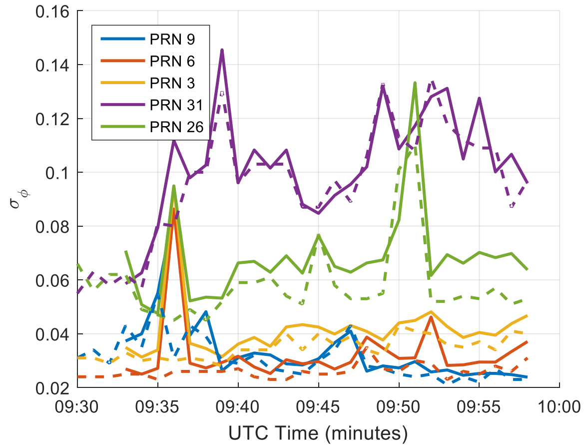
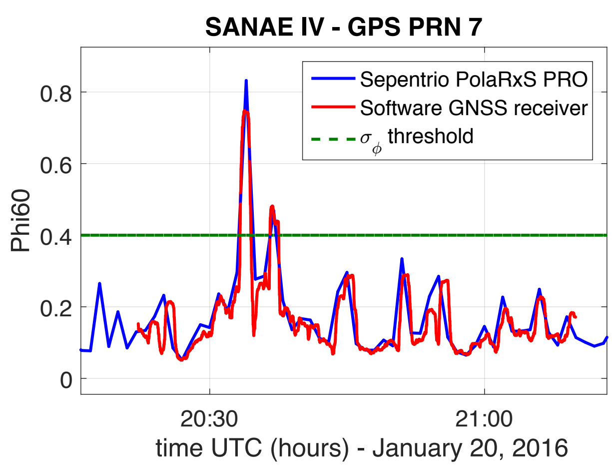


Figure 4. Phase scintillation index, 13 November 2015 – USRP (continuous line) vs. Septentrio (dashed line).

This is further demonstrated, observing the comparison of the results obtained during a phase scintillation event observed on January 20, 2016 at the SANAE IV base detected during the moderate geomagnetic storm of January 20, around 20:30 Universal Time Coordinates (UTC). In this case the results are based on the data collected by the 4TuNE front-end. Such bit grabber has an automatic trigger which is needed to save or not the IF data. It implements a sliding window of the logged data, examining C/N0, elevation azimuth, S4 and SigmaPhi. When the elevation is high enough, the average C/N0 across the sliding window is above a threshold, then it looks at the S4 and the SigmaPhi. If the maximum of either of these two is above a threshold, it decides to keep the IF data dumping a log otherwise it keeps only the information regarding the scintillation indices and the RINEX file. The event has then correctly detected and stored for further processing.



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3. Conclusions

The advantages of the SDR approach, are not only the possibility to replicate with a good match the results of a professional receiver. The total control of the parameters allows for example to obtain the indexes at a higher output rate and as already remarked, to re-play the scenario in order to process it with a "different receiver" that can be implemented acting on the software routines.

Key words: GNSS, TEC and Scintillation, Cloud, Software Radio Receiver, Antarctica

4. References:

[1] S. Shanmugam, J. Jones, A. MacAulay, and A.J. Van Dierendonck, "*Evolution to modernized GNSS ionoshperic scintillation and TEC monitoring*", in Position Location and Navigation Symposium (PLANS), 2012 IEEE/ION , pp.265,273, 23-26 April 2012.

[2] M.C. Kelley, “The Earth's Ionosphere: Plasma Physics & Electrodynamics”, Academic Press, ISBN 13: 978-0-12-088425-4, 2nd edition, 2009.

[3] P. Kintner and T.E. Humphreys. GNSS and Ionospheric Scintillation: How to survive the next solar maximum. Inside GNSS, July-August 2009.

[4] G. Povero, M. Pini, L. Alfonsi, L. Spogli, D. Di Mauro, F. Dovis, R. Romero, M. Le Huy, P. Abadi, V. La The, N. Floury, “Ionosphere Monitoring in South East Asia: activities in GINESTRA and ERICA projects”, Proceedings of the 2015 International Association of Institutes of Navigation World Congress, Prague, Czech Republic, October 20-23, 2015

[5] C. Cesaroni, L. Alfonsi, R. Romero, N. Linty, F. Dovis, S. Vaddake, J. Park, D. Barroca, M. Cobacho, R. Orus. “Monitoring Ionosphere over South America: the MImOSA and MImOSA2 projects”, Proceedings of the 2015 International Association of Institutes of Navigation World Congress, Prague, Czech Republic, October 20-23, 2015

[6] website: *www.demogrape.net*

[7] J. T. Curran, M. Bavaro, A. Morrison, J. Fortuny, "Developing a Multi-Frequency for GNSS-Based Scintillation Monitoring Receiver," Proceedings of the 27th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2014), Tampa, Florida, September 2014, pp. 1142-1152.

[8] [6] S. Peng, and Y. Morton, “A USRP2-based reconfigurable multi-constellation multi-frequency GNSS software receiver front end,” GPS Solutions, 17(1), 89-102, 2013

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