# SDR GNSS RECEIVER

K. Borre, I.A. Kudryavtsev

Samara State Aerospace University, Samara, Russia

rtf@ssau.ru

The Global Positioning System (GPS) has been operational for 20 years and serves approximately 2.5 billion users. At present, the signals broadcast from the GPS satellites are being modernized. The current GPS signal for civilians occupies 2MHz of bandwidth centered on a single radio frequency. The new civil signals will occupy 24MHz of bandwidth spread over three radio frequencies. In addition, new Global Navigation Satellite Systems (GNSS) are being deployed worldwide to complement and compete with GPS. The Russian Federation is rejuvenating their GLONASS system, and China is moving quickly on their worldwide system, called COMPASS. Europe is planning the Galileo system that will place some 27 satellites in orbits similar to GPS. Regional systems are being developed in Japan
and India. With all of these systems, the number of navigation satellites could increase from today's 60 to 120 satellites or more.

Importantly, all of these new satellites will broadcast civil signals at a multiplicity of frequencies. New satellites will provide geometric diversity and the new signals will provide frequency diversity. Over the next decade, satellite navigation will enjoy the benefits of the geometric and frequency diversity described above. These technical advantages will improve the accuracy of stand-alone GNSS from 10 meters to 1 meter. More importantly, these changes will extend the coverage of satellite navigation to include indoor and urban environments. Diversity will also help mitigate the deleterious effects of radio frequency interference (RFI).

However, new vector algorithms are needed to maximize the performance improvements and benefit to society. These algorithms would be placed in the receivers carried by our citizens. The GPS receivers of today process the signals from each GPS satellite separately. More specifically, each receiver has a tracking algorithm to estimate the signal travel delay from each satellite to the receiver. We call this a federated strategy, because the tracker for any given satellite does not interact with the tracker for any other satellite. These individual trackers are comprised of correlators, which are known to be optimum for tracking one satellite. In addition, the federated strategy is reasonably simple to implement using today's processors. However, the federated strategy is far from optimum when multiple satellites are in view. We propose vector processors to aggregate the information from each satellite and share this information. If the signal from one satellite is weakened or blocked by foliage or buildings, then the vector of information from all the satellites is used to continue the tracking of the weakened satellite. This sharing does not occur in today's federated architecture. In essence, sharing is possible because all of the satellite signals are shifted in time by the position and motion of the person carrying the receiver. This common information is called the user state. Vector processors will use the information from all of the satellites in view to improve the estimate of the user state. This common information will then be used to update and refine the tracking estimates of the individual satellites. This strategy differs sharply from the federated architectures where the individual estimators must act by themselves.

Vector processing will help to enable a new set of valuable applications. For example, they will help with safety critical applications in terrestrial environments. So far, the only widespread use of satellite navigation for safety of life applications is aviation, where the GPS antennas are mounted on top of the aircraft free from the effects of reflected signals. We feel that vector processing, along with the improvements in the GNSS constellations, will bring these applications indoors and to cities.

Software defined receivers are needed to maximize the benefit from this heterogeneous and dynamic signal environment. Indeed, most GPS receivers are currently implemented using application specific integrated circuits (ASICs), but these receivers require 24 or more months of development time even with a dedicated and experienced engineering team. We seek a receiver that can accommodate and evaluate the new satellites and signals within weeks, including adaptation to a given platform (processor).

Such a receiver would have high value to GNSS researchers in academia and university laboratories. It would also have high value to industry, because it would enable the rapid evaluation of new signals and signal processing techniques. In other words, it would significantly shorten the design cycle.

Vector processor, based on SDR approach, can be utilized as the core engine of high, medium, and low accurate receivers. The market for the high end receivers is limited, but the markets for the medium and low accurate receivers are nearly unlimited.

The area of applications for the high accurate receiver is land surveying, docking of ships in harbors, surveillance of huge man-made constructions (bridges, tall buildings, nuclear power plants), monitoring of the earth’s crust in tectonic active areas, precision farming, and robotic guidance. The medium accurate receiver is ideal for intelligent transport systems, automatic payment of parking charge, surveillance of livestocks, tracking of animals, and surveillance at protected homes. The low accurate receiver will typically be used in cellular phones, for car guidance, tracking of items, leisure boats, geocaching, and tracking of items that are likely to be stolen.

In short, there is a huge potential in changing the way GNSS receivers are manufactured and a great potential for many more future applications. We plan to bring the receiver technology a step further for the benefit of society and human beings.

Any GNSS is composed of three parts: The space segment (satellites), the control segment (tracking facilities at several spots and a main computational facility), and the user segment. This threefold split makes it possible to manufacture cheap user units, also called receivers. Traditionally GNSS receivers are manufactured as hardware. This means once a receiver is manufactured, it becomes difficult to modify.

Conceptually this situation changed in 1997 when Dennis Akos introduced the concept of software defined radio (SDR) for GPS. At that time the technological facilities were not ready for actual implementation. This happened ten years later. In 2007 a group at Aalborg University and Dennis Akos published a dedicated textbook, which included a DVD containing code for a GPS software defined receiver. The programming language was Matlab. That book had a tremendous impact on the profession.

Suddenly many developments in academia started using the software concept. SDR is a rapidly evolving technology that is getting enormous recognition and is generating widespread interest in the receiver industry. SDR technology aims at a flexible open-architecture receiver, which helps in building reconfigurable SDRs where dynamic selection of parameters for individual modules is possible. The receiver employs a wideband analog-to-digital (A/D) converter that captures all channels of the software radio node. The receiver then extracts, downconverts, and demodulates the channel waveform using software on a general-purpose processor. The idea is to position a wideband A/D converter as close to an antenna as is convenient, transfer those samples into a programmable element, and apply digital signal processing techniques to obtain the desired result. An SDR is an ideal platform for development, testing of algorithms, and possible integration of other devices.

An SDR tries to identify the signals present in the collected data sets. This acquisition happens by using serial or parallel search methods. After a GNSS signal is acquired, the code and carrier tracking and data demodulation follows. Various delay lock loops (DLL) discriminators are used for this purpose. A phase lock loop (PLL) and a frequency lock loop (FLL) are often used to track a carrier wave signal. These elements are critical to refining the precise observations provided in GNSS. We recover the navigation data and convert them to ephemerides. An ephemeris makes the basis for computing a satellite position. Next we need to estimate the raw and fine parts of the transmit time. With these combined data we introduce a computational model that delivers the receiver position. Fig. 1 represents a hardware board, which was used to develop and test main algorithms.


Fig. 1: The DGC receiver

A software defined receiver is typically composed of 12 channels. A hardware or software receiver using GPS the C/A code on L1 yields position accuracy better than 10 meters. If a user wants a better accuracy, he may start by eliminating the ionospheric delay. This is accomplished by using a dual frequency receiver as the ionospheric delay is frequency dependent. This receiver also eliminates orbital and clock errors. In addition to L1, GPS transmits signals on L2 and in near future even on L5. All these signals become available for civil users. That is, we have a possibility of building a triple frequency receiver.

An alternative procedure for eliminating the ionospheric delay is to exploit a satellite based augmentation system (SBAS) such as the European Geostationary Navigation Overlay System (EGNOS), Wide Area Augmentation System (WAAS), or the Russian System for Differential Correction and Monitoring (SDCM). In addition one gets integrity information.

A further augmentation is to establish a multi-system SDR. Today the commercial hardware market offers combined GPS and GLONASS receivers. Our long-term project will prepare for GPS, GLONASS, Galileo, and COMPASS. So the path from a single channel to a single frequency receiver (12 channels) to dual/triple frequency receiver (24/36 channels) to a multi-system receiver (more than 100 channels) is long and complicated. In the future it is likely that the market rather than asking for a 100 channel receiver asks for a receiver based on a combination of a few of the most relevant signals for a particular task. So the future receiver most likely is dedicated to a specific task rather than being a standard one. This again asks for flexibility and modularity in the receiver architecture. Here the SDR concept is eminent.

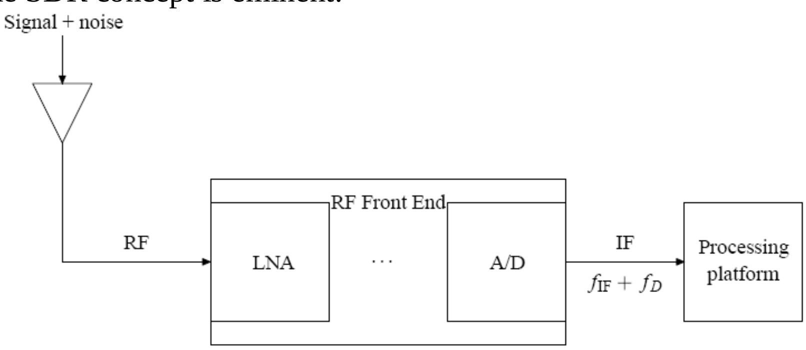


Fig. 2: Radio Frequency (RF) and Intermediate Frequency (IF) signals, Low Noise Amplifier (LNA), Analog-to-digital (A/D) converter, and processing platform

One of the most important issues is signal authentication. A GPS-based authentication answers the questions: How do you know you are where you think you are? How do I know you are where you say you are?

Ideally the civilian parts of the GNSS would have some security built-in. Like for the internet the original idea was not considered for the civil parts of GNSS. The Galileo system possibly will offer such a feature which has to be paid for. The option is still years ahead.

Spoofing is the situation where a person tries to cheat the user to believe that his position is different from his true position and the user is not aware of this situation. He is spoofed!

By hacking the satellite-to-receiver signals, GNSS is opened up for the same type of attack as the ones that is a daily plague for laptops, main frames, and the internet.

The proposed receiver will use so called snap-shot technique. As described in Figure 2, the complete receiver consists of antenna, front-end, and processing platform. In several applications it is tempting to move the processing platform to a common server and let this server do most of the signal processing and final position computation. This comes with the price that we need to transmit the digital data from the front-end to the server. The obvious gain is that the physical part becomes smaller and cheaper and in fact the position computation at the server delivers more accurate, more reliable and authenticated results. These benefits are so great that they outperform the difficulties and costs by using a real time transmission. The transmission can happen either as an SMS or better, and more flexible, by using a portable internet connection.

In case such a connection can not be established, the data must be kept on a nonvolatile storage and transmitted later on.

Using these necessary units, the security problems are moved from the vehicle to the reliable authentication server. This strategy reduces costs and moves the fragile part from all users to the few distributed servers.

In the vicinity of each server a complete dual frequency receiver, including SBAS, must operate. This provides position, time, estimation of ionospheric delay, a necessary part of the authentication procedure, etc.

This splitting of the complete receiver into two parts is named snap-shot technique. We do not transmit the total sequence of digitized signals, but only short selected periods of these, typically 20 ms. Only these short cuts of the signals are packed and transmitted to the server. A 20 ms sequence typically is a few kilobytes of data for one GNSS.

Development of this new GNSS receiver is planned to continue in research laboratory, which is being created in SSAU. Till the end of the year we are coding a Matlab model of the receiver, using the opportunities of the supercomputer Sergey Korolyov. In 2015 creation of an FPGA based prototype is expected.

*References*

*1. Sennott, J. & Senffer, D. (1992) The use of satellite constellation geometry and a priori motion constraints for prevention of cycle slips in a GPS signal processor, Navigation, volume 39, pages 217–236*

*2. Spilker, J. (1996) Fundamentals of Signal Tracking Theory. In Global Positioning System: Theory and Application Volume I, edited by B. Parkinson and J. Spilker, Progress in Aeronautics and Astronautics, volume 163*

*3. Kanwal, Nazia & Hurskainen, Heikki & Nurmi, Jari (2010) Vector Tracking Loop Design for Degraded Signal Environment. Ubiquitous Positioning Indoor Navigation and Location Based Service (UPINLBS). IEEE*

*4. Lo, Sherman & de Lorenzo, David & Enge, Per & Akos, Dennis & Bradley, Paul (2009) Signal Authentication. A Secure Civil GNSS for Today. InsideGNSS, pages 30–39, September/October*