GALILEO/GPS RECEIVERS FOR GEODETIC APPLICATIONS

Andrew Simsky(Septentrio, Belgium a.simsky@septentrio.com*),*
Jean-Marie Sleewaegen (Septentrio, Belgium jm.sleewaegen@septentrio.com*),*

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Introduction

Septentrio specializes in the design and manufacturing of high-end GNSS receivers including all the steps of HW and SW implementation: RF part, broadband chipset, board design, firmware etc. We are currently involved in a number of ESA-supported projects related to the development of Galileo, the new European GNSS system. Septentrio is developing Galileo receivers for the testing of the future system and for a variety of professional applications including geodesy, reference station networks and surveying. This paper presents an overview of our Galileo activities including ongoing projects and future developments.

The paper begins with an overview of Galileo signals and their advantages over GPS signals. Then we define the Galileo observables as they are foreseen in our receivers. Further, we describe Septentrio's Galileo-related projects and present main architectural concepts of the new generation of receivers.

Galileo signals

Galileo transmits signals in 4 frequency bands: E5a, E5b, E6 and L1. Figure 1 shows the general view of the Galileo spectrum.

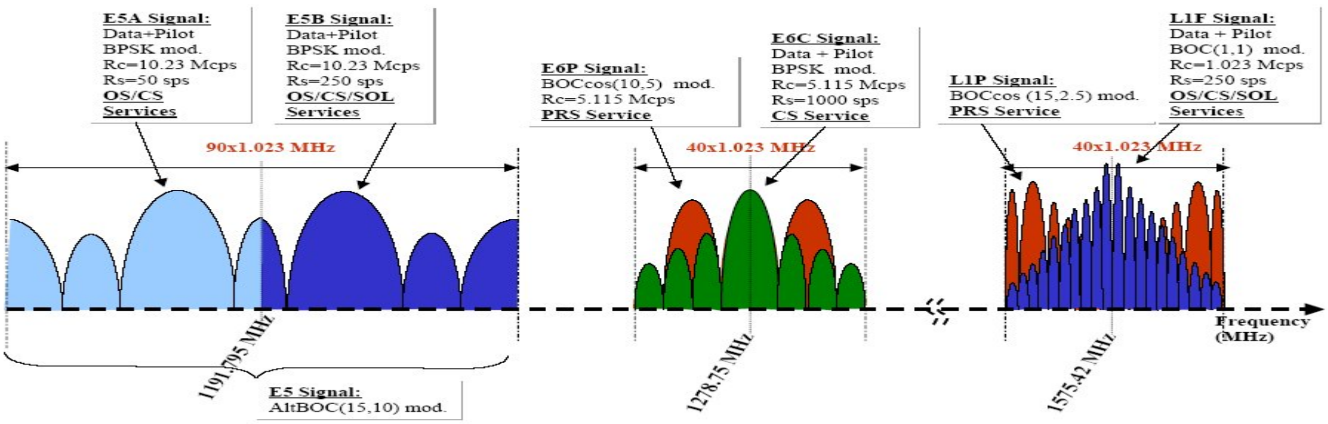

Figure 1. Overview of Galileo signals

The list of signal components is presented in Table 1. Although the principles of Galileo are quite similar to the principles of GPS, Galileo will offer a much greater variety of signals and services. The design of Galileo signal structure presents significant user advantages as compared to the current GPS:

- The power of Galileo signals will be greater by a factor of 2, which will result in the reduction of tracking noise for both phase and code ranges.

- Each Galileo signal includes a so-called "pilot", data-less component, which can be easily acquired independently from the decoding of data bits. This will have a big positive impact on rover-side RTK applications, because the re-acquisition of phase after the loss-of-lock will be a lot faster than in the case of GPS, where both signals are modulated with the navigation data.
- The novel modulation schemes will result in significant reduction of both tracking and multipath noise for all the code ranges. One of the new signals, E5-AltBOC will have exceptionally low noise characteristics. (See one of the later sections for more details).
- A more robust 3-step coding scheme for navigation bits will be used (Viterbi-encoding, CRC check, bit interleaving). This will significantly increase the reliability of navigation message decoding in the presence of interference or with low signal power.

Signal no.	Signal	Carrier frequency (MHz)	Channel designation	Symbol rate Navdata (symbols/s)	Notes [1)]
1	Data signal in E5a*	1176.45	E5a-I	50	OS; open, no encryption
2	Pilot signal in E5a*	1176.45	E5a-Q	-	No data
3	Data signal in E5b*	1207.14	E5b-I	250	OS, SoL; open, no encryption
4	Pilot signal in E5b*	1207.14	E5b-Q	-	No data
5	Data signal in E6	1278.750	E6-A	Classified	PRS; encrypted code and data
6	Data signal in E6	1278.750	E6-B	1000	CS, encrypted code and data
7	Pilot signal in E6	1278.750	E6-C	-	No data, code encrypted
8	Data signal in L1	1575.420	L1-A	Classified	PRS; encrypted code and data
9	Data signal in L1	1575.420	L1-B	250	OS, SoL; open, no encryption
10	Pilot signal in L1	1575.420	L1-C	-	No data

Table 1. Galileo signal components.

***The satellites will transmit the E5a and E5b signals as one wide-band modulation referred to as "Alt-BOC", centered at 1191.795MHz.**

It can be seen from Table 1 that Galileo will offer a wide variety of services: open, safety-of-life, commercial and publicly-regulated. This variety of services and related user applications is outside the scope of this paper as well as the new integrity concept, which will significantly increase the reliability of the Galileo navigation solution. In this paper we shall keep focus on the signal tracking aspects and those qualities of the future receivers, which are most essential for geodetic applications.

In-orbit testing of Galileo signals within the framework of GSTB (Galileo System Test Bed) will begin in the end of 2005. In order to validate the principles and implementation of Galileo signals, two test satellites are scheduled to begin the transmission of Galileo signals in December of 2005. Actual deployment of Galileo constellation will begin in 2008 when 4 first operational satellites will be launched.

Galileo observables

Galileo observables are user measurements provided by Galileo receivers. Each Galileo observable is (similarly to GPS) a set of 4 measurements, which includes a code pseudorange, a carrier-phase measurement, a Doppler (or a range rate), and an SNR (signal-to-noise ratio). The design of Galileo signals implies that data and pilot components of each signal are tracked together and result in one measurement.
Indeed, both data and pilot components carry the same code modulation and have exactly the same noise characteristics. Although it is technically possible to track either the pilot or the data component separately, this would lead only to the reduction of signal-to-noise ratio without gaining any new information.

No.	Signal	Components	Carrier frequency (MHz)	Notes
1	E5a	I+Q	1176.45	= GPS L5
2	E5b	I+Q	1207.14	
3	E5a+b (Alt-BOC)	Q+Q	1191.795	Low-noise signal
4	E6	B+C	1278.750	
5	L1	B+C	1575.420	= GPS L1

Table 2. Currently foreseen Galileo observables

The list of currently foreseen Galileo observables is presented in Table 2. (Classified receivers will also have access to E6-A and L1-A observables.) For each frequency band there is one observable obtained by co-operative tracking of pilot and data components. Due to the Alt-BOC modulation scheme, co-operative tracking of both E5a and E5b signals is possible leading to a high-performance Alt-BOC observable. The tracking of the Alt-BOC uses the whole 90 MHz-wide bandwith of E5a+b signals, which results in a higher value of the effective modulation rate and low noise characteristics.

Multipath performance and tracking noise of Galileo codes

Figure 2 demonstrates anticipated multipath performance of Galileo ranging codes.

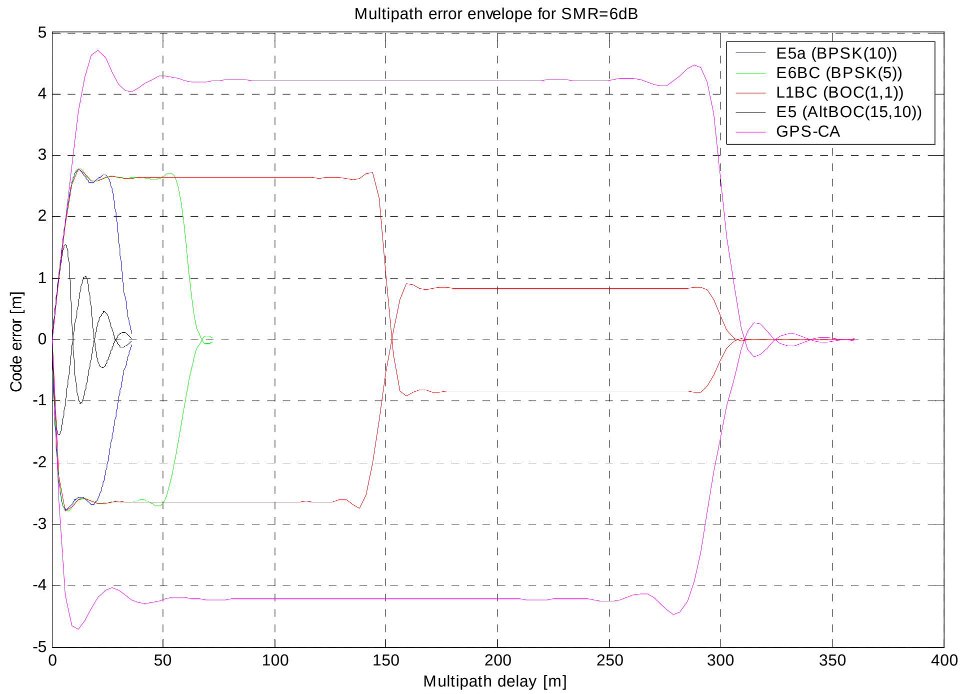

Figure 2. Multipath error envelopes for Galileo codes in comparison with the C/A code

It can be well seen that the multipath performance of all the Galileo codes is superior as compared to the C/A code, which is the only GPS code currently available for direct tracking (the future GPS L2C signal will have the same multipath performance as the C/A code). It is noteworthy that the multipath performance of the Galileo BPSK(10) code is identical to the performance of the of the GPS P-code, which is not available for civilian geodetic receivers. Among all the signals, the multipath performance of the Galileo Alt-BOC modulation is by far the best. It should be stressed that even the short-range multipath errors, which are the most difficult to handle but quite common in real-life environments, are significantly reduced.

Tracking noise of Galileo codes is presented in Figure 3. It can be well seen that all the Galileo codes have significantly lower tracking noise as compared to the C/A code. The tracking noise of the Alt-BOC pseudoranges is lower than the tracking noise of the C/A code by a factor of 10. It appears that Galileo receivers will bring tracking noise figures from dm-level down to cm-level values.

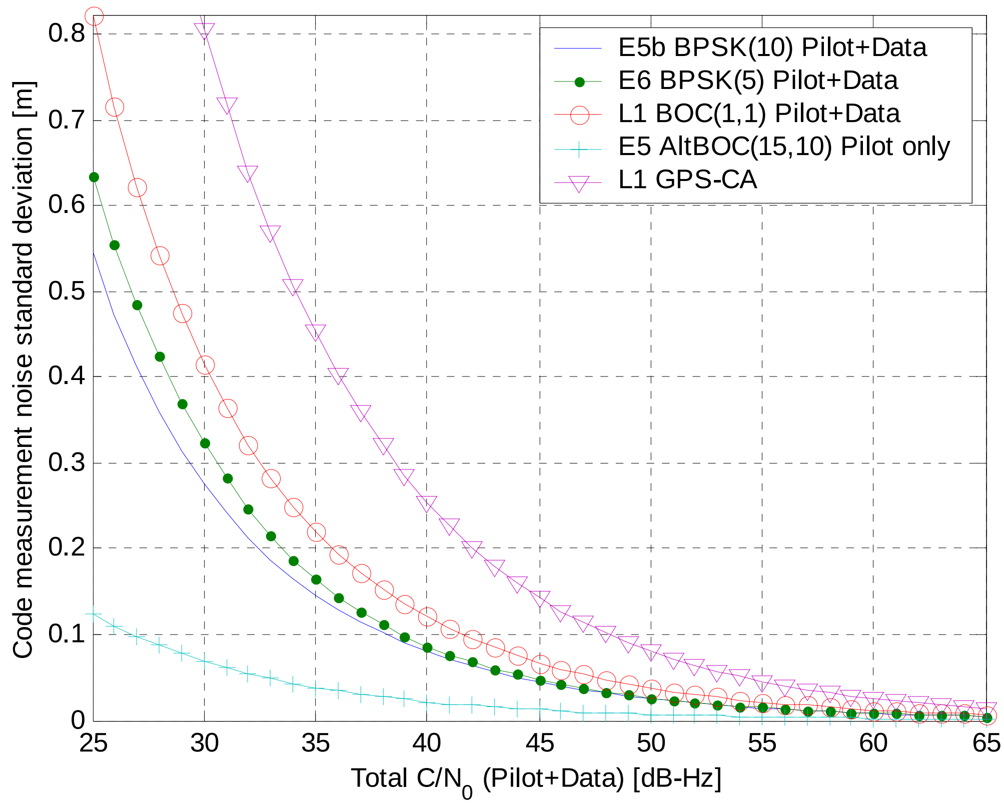

Figure 3. Tracking noises of Galileo code ranges as a function of signal-to-noise ratio

It should be noted that the future, modernized GPS satellites will also transmit improved code modulation schemes. The first new GPS signal is the well-known L2C, which is scheduled to appear in 2005. Although the L2C signal has a more complex structure than the C/A code and present a big improvement relative to the current GPS L2 signal, the noise characteristics of the L2C signal (both multipath and tracking noise) are identical to that of the C/A code. As for the future GPS L5 signal, which deployment is scheduled to begin in 2010, its noise characteristics are likely to be very similar to that of the Galileo E5a signal.

Septentrio's Galileo receiver projects

Septentrio plays the leading role in the design of Galileo user receivers at all the stages of the Galileo program, from early testing to final deployment and the development of commercial user receivers for versatile precision-demanding applications.

GSTB-V2 receivers

The first Septentrio's Galileo receiver has been released in the end of 2004[1] and has been already used for end-to-end verification of the payload of the two early versions of the Galileo satellites, called the GSTB-V2/A and /B satellites (Figure 4), planned for launch in December 2005. It has also been used for the acceptance of the Galileo Signal Validation Facility (GSVF). These early tests have demonstrated successful tracking of all the modulations planned for Galileo, including the most promising Alt-BOC.

GSTB-V2 / A

Lift-off mass 600 kg
Power demand 700 W
Stowed Dimensions:
1.3 m x 1.8 m x 1.65 m

GSTB-V2 / B

Lift-off mass 495 kg
Power demand 760 W
Stowed Dimensions:
1.0 m x 1.0 m x 2.4 m

Figure 4. GSTB-V2 satellites

The second version of the GSTB test receiver is already available at the time of this writing. It is named GETR (Galileo Experimental Test Receiver) and is shown in Figure 5.

Figure 5. Septentrio's GSTB-V2 test receiver in the lab

The GETR receiver is able to track simultaneously 4 general Galileo signals (+ one Alt-BOC signal) and 9 GPS satellites (L1+L2). The receiving capabilities of GETR perfectly match the transmitting capabilities of the GSTB-V2 satellites. Each satellite will transmit only in 2 frequency bands at a time; the signals will be switched by the commands from the ground. Users of the test receiver will have to switch the allocation of tracking channels accordingly.

The GETR will provide measurements for all the Galileo and GPS observables (see Table 2) and compute positional solution based on GPS signals. The raw bits of the Galileo navigation messages as well as decoded navigation data records will also be available for logging.

To support in-depth analysis of the new signals, the GETR features unique functionalities like real-time monitoring of the correlation peak profile or Intermediate Frequency (IF) samples logging. It is not only compatible with the GSTB-V2 satellites: it will also support tracking of the signals of the actual operational Galileo satellites to be launched in 2008.

Galileo test user receiver

For the testing of the future Galileo system, Septentrio is developing a fully-fledged multi-frequency Galileo/GPS receiver capable to track all the Galileo signals and compute the positional solution using either both systems together or each of them separately. This receiver will also track GPS L1 and L5 signals. This receiver will be able to track simultaneously up to 12 Galileo satellites + 12 GPS satellites.

The Galileo navigation solution will benefit not only from the lower noise of Galileo measurements, but also from the reduction of orbit and clock errors and from the improvements in the modeling of atmospheric delays. In particular, a novel ionospheric model will significantly increase positional accuracy for single-frequency users as compared to the current Klobuchar model of GPS.

Flexibility is an important feature of the test user receiver: it is expected to cover all the Galileo services [2]. The test receiver will be used to verify user requirements to all the Galileo services in a number of pre-defined user environments (urban, rural, etc.).

Commercial Galileo/GPS user receivers for precision-demanding applications

With an ever-growing number of GNSS systems, frequencies, and signals, receiver designers will have to make practical choices of signals to be used in future receivers. Advantages of using additional ranging information must be weighed against the disadvantages of increasing the weight, power consumption, and cost. The general tendency is that including an additional frequency band makes a greater burden than processing an additional satellite system, because not only additional tracking channels, but also additional front-end HW blocks must be added. With the greater number of frequency bands to be covered, the antenna design is getting more complex and expensive as well.

The dual-frequency dual-system Galileo/GPS L1/E5a receiver is generally considered as a typical RTK receiver of tomorrow (see, for example, [3]). Numerical analysis of success rates for the fixing of integer RTK ambiguities had been performed in [4] for a few open-sky scenarios, which represented different combinations of GNSS systems and frequencies. It was concluded that dual-frequency GPS+Galileo is the best of all the considered scenarios, although the triple-frequency Galileo produced comparable results.

The main rationale to use only these two frequency bands is that they are common for GPS and Galileo and have the maximal frequency separation. Another advantage is the simplicity of antenna design: dual-frequency L1/E5a antennas will probably be typical antenna products at the time when Galileo comes into being; in fact the same sort of antenna has to be developed for GPS L1/L5 receivers. The matching Galileo and GPS pairs of observables (Galileo L1/E5a and GPS L1/L5) will have exactly the same frequency ranges and similar noise characteristics. There will be no analogue of Galileo Alt-BOC in GPS, hence this unique signal will be specific to Galileo receivers.

Note on the architecture of Galileo receivers

Due to the conceptual similarity of Galileo and GPS, the high-level architecture of Galileo receiver is similar to high-level architecture of GPS receivers. The essential new element of the new generation of receivers is a so-called “generic channel”, a channel, which is able of tracking all the foreseeable modulations including the known codes for Galileo and GPS. The baseband chip of future receivers will represent a matrix of generic channels. Future receivers built around this concept, shall use flexible allocation schemes of channels to signals.

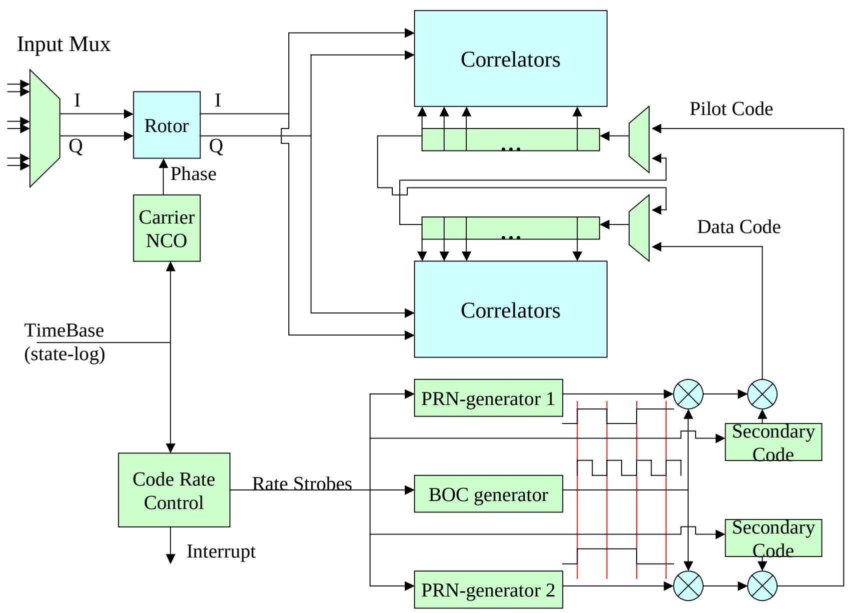

Figure 6. Generic channel architecture

The sketch of the generic channel is presented in Figure 6. One of the main differences between the current CA-code signal and the Galileo signals (or the GPS L5 modernized signal) is the presence of a data-less pilot component associated to the data-bearing signal. With the channel architecture shown in Figure 6 both the pilot and data components are demodulated in parallel.

The demodulation works as follows. The input signal can be selected from any of the three Galileo bands (L1, E6 or E5). The residual carrier (Doppler) is removed by mixing the incoming signal with a digitally generated complex carrier. The spreading codes for pilot and data are generated by two code generators, which can be configured to generate any Galileo or GPS spreading code. Thanks to the coherence between the pilot and data components, a single rate-control unit controls the rate of both codes. This unit also controls the rate of the (flexible) sub-carrier needed for BOC modulation. The same sub-carrier can be used for pilot and data signal. In normal mode both locally generated signals enter two delay lines. The time-shifted signal replicas created in this way are correlated with the incoming base-band signal, producing all correlation values needed for code and phase tracking, side-peak lock detection and multipath mitigation.

The new receivers shall not need indirect tracking schemes currently in use for GPS L2 (codeless or semi-codeless). All the codes of future GNSS systems will be tracked directly.

Conclusions.

Galileo is the new European GNSS system. Galileo signals will offer significantly higher performance characteristics than current GPS, the only fully available GNSS system of today. The unique Galileo AltBOC signal has exceptionally low multipath and tracking noise.

This paper contains a brief overview of Galileo receiver projects in which Septentrio is currently involved. The first actual Galileo receiver will be available end of 2005 for the testing of the signal transmitted by GSTB-V2 satellites. A complete GPS/Galileo test user receiver will track all the Galileo signals and all the GPS signals available in the matching frequency bands (L1 and L5). The future design of the RTK receiver is also discussed.

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