THE GREHDA PROJECT: GALILEO SOFTWARE RECEIVER FOR HIGH DYNAMIC APPLICATIONS

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INTRODUCTION

The GREHDA project (GALILEO Software Receiver for High Dynamic Applications) is funded by the Galileo Joint Undertaking under the 6th Framework Program, and addresses the design of Galileo receivers for space applications with limited financial and engineering budgets. The project objectives are: to design, develop and validate high-dynamics tracking and acquisition algorithms by means of dedicated simulation tools; to propose a conceptual design of the receiver basic hardware and software platforms; to define a flight technology validation experiment to test such algorithms in the real environment

The team is composed by Carlo Gavazzi Space (Italy), acting as Consortium Coordinator and responsible for project management, engineering coordination, market analysis, algorithms validation, receiver conceptual design, flight experiment definition and final data dissemination; Politecnico di Torino (Italy), responsible for analysis, development and implementation of high-dynamics algorithms, and contribution to receiver preliminary design; DLR (Germany), responsible for high dynamic trajectory modeling, and support to algorithms implementation.

STUDY LOGIC

The project will last 16 months, and is subdivided in three main phases.

During the *Consolidation Phase*, a detailed assessment of Galileo signals as received by high dynamic vehicles, as well as survey on the state-of-the-art of Spaceborne GPS receiver technologies have been carried out, together with a dedicated analysis on specific market requirements and opportunities.

The *Implementation Phase* started with a preliminary design of the specific signal processing algorithms for high dynamic applications, during which extensions of pre-existing Galileo signal simulators and analysis tools have been developed. These involve the modeling of high dynamic trajectories, mainly for LEO satellites and sounding rockets, and the generation of the digitized signal at IF, as seen by the correlators. The next step includes the design and implementation of basic signal processing algorithms, including acquisition strategies and schemes, as well as steady-state code and carrier tracking structures, into a single-channel SW receiver. The tool selected for such implementation is the NordNav R30 R&D SW Receiver, equipped with Galileo extension, because of the appropriate framework provided by its acquisition and tracking Application Protocol Interfaces (API). The characterization of the main receiver performances will be carried out during the validation campaign, using raw IF data from high dynamic scenarios. Another task being accomplished during this Phase is the preliminary architectural design of a Software Defined Radio (SDR) Galileo receiver.

The objectives of the *Transfer Phase* are to identify a flight technology validation mission, which will allow testing of the algorithms validity and robustness in the real environment, and to disseminate the results of the entire project to the relevant user community, by means of participation to appropriate workshops and presentation of the project outcomes to international conferences.

ANALYSIS OF MARKET REQUIREMENTS AND OPPORTUNITIES

Space market structure is segmented in two main directions: the space applications (small satellites, small expendable launch vehicles, private space vehicles) and the actors (final users, customers and founders). In particular, the actors could be combined in nearly any possible way among themselves and, because of this peculiarity, such dimension is the farthest from a common market and strongly characterize the space market.

Market Segmentation by Main Actors

In most of the markets, who uses, who selects the product and who buys it is usually the same person, or in any case belonging to the same homogeneous group (family, company). On the space market, instead, they are different people belonging to different groupings (companies, governmental bodies, universities, etc.). These main groups can be identified with: final users, customers and founders. *Final users* are those actually drafting specification for the space system. They are groups of scientists in the case of scientific satellites, or telecommunication companies in the case of commercial telecom satellites. *Customers* are directly requesting the space system to a space system provider. They are usually referred at as “Agencies”. Sometimes, the Customer is also a provider, a final user and the founder. *Founders* are the ones who pay for the space system. Usually, they are ministries or specific committees of the governments, or even single bodies depending on them. Recently, the interest for space tourism and for private space initiatives has attracted also private funds like finance investors, venture capitalists and general entrepreneurs.

According to this grouping, some typical actors playing in the space market can be identified. *Governmental and military* typically develop programs for the security of the Countries and they have not big limitation in budgets, but they require elevate precision, continuity and, possibly, security of the system. *Multi-national agencies and companies* develop scientific projects and research programs. They use small technologies for satellites and rockets in order to reduce the mission complexity, costs and organization times. The accuracy and the precision of the results they want to obtain is the main task to consider. *Private societies* usually offer services to a different kind of public. Often they have lower degree of accuracy in their applications, and they have reduced budgets. *Amateur and private* utilize satellites or space vehicles for private scopes, usually not open to the public. Small satellites can be used to test future scenarios or to experiment the capabilities of new technologies.

Market Segmentation by Applications

Small and Low-Cost Satellites make up the largest market segment, with an average world production of about 24 small satellites (mini, micro and nano satellites) per year (in the last 20 years). With the current pressure, driven by agencies, on further reducing costs while improving performances, space system providers are forced to search for efficient solutions, like GNSS receivers, having a minimal impact on the bus (low mass and power consumption, low cost) and allowing for a higher autonomy of the space segment with respect to ground operation (reducing operation costs).
Small and Expendable Rockets constitute a smaller market with respect to small satellites, but more stable and less influenced by world economic trends, mainly because they are able to launch also mid-sized satellites as well as large

satellites, but in LEO. Although the market appears quite "static" in term of new products, existing launch vehicles are continuously upgraded for cost optimization, thus leaving room for the penetration of cost efficient GNSS receivers.

Sounding Rockets, a small niche market segment, are mostly used for atmospheric experiments. They are small, cheap and based on straightforward technology. By flying mostly within small ranges, their flights can be tracked by various means. A GNSS receiver would be interesting for this application only if experiments are starting to require a high precision in terms of positioning and time (plasma phenomena are very scale dependent).

Private Space Vehicles make up a potentially expanding niche market segment. These users will be extremely price sensitive and also very concerned about reliability and crew safety, mostly because many of them are going to actually operate in the field of space tourism, i.e. manned missions (even if just trans-atmospheric ones). They will likely be reusable vehicles, keeping the numbers of GNSS receivers low and mainly driven by upgrading and refurbishing needs.

SURVEY ON SPACEBORNE GPS RECEIVERS TECHNOLOGY STATE-OF-THE-ART

While the basic functionality of a spaceborne GPS (SGPS) receiver is the same as that of a terrestrial or aeronautical receiver, its design has to properly account for the high signal dynamics and the hostile environment in which theses receivers are operated. Whereas the signal tracking aspects can be handled by suitable adaptations of the receiver software, the environmental robustness of space equipment is a continued source of concern. Dedicated engineering and qualification standards have been established by relevant space agencies and satellite manufacturers, including resistance to thermal-vacuum conditions, vibration and shock loads as well as ionizing radiation and single event effects. A cost driving test and qualification effort is implied by these standards, moreover suitably qualified electronic components are less powerful and require higher resources (mass, power) than state-of-the art consumer electronics.

The small market segment and high specialization of SGPS receivers as well as the associated test and qualification effort inevitably results in high unit cost, ranging from roughly 100 k€ to 1 M€. Various companies and research institutes have therefore made efforts to come up with low cost solutions based on the use of commercial-off-the-shelf (COTS) components. The feasibility of this approach is nicely illustrated by the GPS Orion receiver design of Mitel, which forms the basis of SSTL's "Space GPS Receiver" (SGR) series as well as independent developments at Stanford University, Cornell University, Tsinghua University JSC, GSFC, and DLR. More recently, the use of COTS technology has also been proposed for geodetic grade dual-frequency receivers with a first flight demonstration being planned for 2007. It must be kept in mind, however, that COTS components should not be used without appropriate qualification testing even if the mission allows for a relaxation of quality assurance requirements and tolerates increased failure risks.

Single-frequency GPS receivers constitute the majority of satellite navigation systems currently employed onboard Earth-orbiting spacecrafts. They are primarily used to obtain position, velocity and timing information onboard the host vehicle in real-time. The accuracy of the Standard Positioning Service is largely sufficient for this purpose and the employed receivers are generally more robust and require lower system resources than their dual-frequency counterparts.

An overview of available systems provided by European and international manufacturers in provided in Table 1. It comprises dedicated space receivers built from rad-hard semiconductor devices (Topstar-3000, MOSAIC, TENSOR) as well as various receivers based on COTS components (SGR, Phoenix, Viceroy, TANS Vector) with lower radiation tolerance. Depending on the particular design and capabilities, the power consumptions of individual ranges from less than 1 W up to an extreme value of 25 W. The real-time navigation accuracy is typically 10 m, with availability and (in part) accuracy improved in some cases thanks to supplementary Kalman filters.

HIGH DYNAMICS TRAJECTORY MODELING

As part of the GREHDA study, an existing GALILEO signal simulation tool will be extended to support high dynamics trajectories. To minimize necessary adaptations, it has been decided to employ a tabular trajectory file with Cartesian position and velocity data as the sole source of orbit information for the simulator. In this way, both ballistic trajectories and satellite orbits can be handled in a flexible manner.

For Satellites in low Earth orbit (LEO), a standalone software package (SIMEPH) has been developed to generate a trajectory file from a given set of orbital elements. It performs a numerical integration of the initial state vector in an Earth-fixed reference frame, taking into account orbital perturbations from the aspherical Earth, luni-solar gravity, atmospheric drag, and solar radiation pressure. Besides predicting the spacecraft motion over a user configurable interval, the SIMEPH tool can also provide a representation of the trajectory in the form of GPS broadcast ephemeris elements. This provides a compact and convenient representation of the host vehicle motion inside a GNSS receiver and can be used to facilitate the initial signal acquisition under high dynamics.

Table 1. Single Frequency spaceborne GPS Receivers.

Manufact.	**Receiver**	**Orig**	**Nav. Acc. (SPP/KF)**	**Power Weight**	**TID [krad]**	**Temp. Range**	**Missions**
Alcatel	TopStar 3000	F	- / 10m	1.5 W, 1.5 kg	>30	-25°C / +60°C	Demeter, Kompsat-2
EADS Astrium	MosaicGNSS	D	20m / 10m	10 W, 1 kg	>30	n/a	TerraSAR-X, SARLupe, Aeolus
Laben (SS/L)	Tensor	I	n/a	15 W, 4 kg	100	-40°C / +71°C	Globalstar, SAC-C, ATV
SSTL	SGR-05	GB	10m / -	0.8 W, 20 g	>10	-20°C / +50°C	
	SGR-10	GB	10m / -	5.3 W, 1 kg	>10	-20°C / +50°C	Tsinghua-1, AISAT-1 UK-DMC
	SGR-20	GB	10m / -	6.3 W, 1 kg	>10	-20°C / +50°C	PROBA-1, UOSat-12, BILSAT-1
DLR	Orion-S	D	10m / -	50g, 2 W	15	-20°C / +85°C	PCsat
	Phoenix-S	D	10m / 2 m	20g, 0.9 W	15	-20°C / +70°C	Proba-2, X-Sat, PRISMA
BAE/ROKAR	GPS SpaceNav	ISR	15m / -	6 W, 1.6 kg	20	-25°C / +60°C	
NEC/Toshiba	GPSR	J	n/a	25 W, 8 kg	10	-15°C / +55°C	Adeos-2
General Dynamics	Viceroy	US	30 m / -	4.7 W, 1.2 kg	15	-20°C / +60°C	MSTI-3, Seastar, MIR, Orbview, Kompsat
Trimble	TANS Vector	US	n/a	7.5W, 1.4 kg	8	-40°C / +65°C	REX, AO-40, GravityProbe-B
	Force 19	US	n/a	n/a	n/a	n/a	ISS
SpaceQuest	GPS-12	US	n/a	1.6 W, 50 g	n/a	-20°C / +60°C	n/a
RIRT	Kotlin K-161	RU	n/a	2 W, 100 g	n/a	-30°C / +70°C	ISS (?)
Accord (ISRO)	NAV2000HD	IND	15 m / -	7.5W, 0.8 kg	n/a	n/a	IRS-P3
	NAV2000HDCP	IND	20 m / -	2.5W, 50 g	n/a	n/a	X-sat

HIGH DYNAMICS ALGORITHMS ANALYSIS AND PRELIMINARY DESIGN

Analysis of Galileo Signal for Space Applications

The focus of the GREHDA project is the Galileo Open-Service (OS) signal in L1 band, which is the most suitable for low-cost and low-power receivers. Such signal is more complex than the GPS one, since it consists of the multiplexing of three components referred to as L1-A (data channel of the Public-Regulated Service), L1-B (data channel of the Open-Service signal) and L1-C (pilot channel of the Open-Service signal). The signal broadcast by GIOVE-A (the first of the two satellites for the Galileo In-Orbit validation phase) is described in [1], while the GIOVE-A L1-B Primary, L1-C Primary, and L1-C Secondary Codes have been published in [2]. The three components of the L1 signal are multiplexed using a CASM modulation [3], which ensures a constant envelope of the transmitted signal. Equation (1) shows the analytical expression of such a signal, where f_{L1} is the L1 carrier frequency at 1575.42 MHz, P_{L1} is the overall transmitted power, and $\alpha_{L1} = \sqrt{2/3}$, $\beta_{L1} = 2/3$ and $\gamma_{L1} = 1/3$ are coefficients designed according to the following transmitted power division: L1-A at 50%, L1-B at 25%, L1-C at 25%.

$$S_{L1}(t) = \sqrt{2 \cdot P_{L1}}\left[\alpha_{L1} e_{L1-B}(t) - \alpha_{L1} e_{L1-C}(t)\right] \cdot \cos(2\pi f_{L1} t) - \sqrt{2 \cdot P_{L1}}\left[\beta_{L1} e_{L1-A}(t) + \gamma_{L1} s_{L1,\mathrm{int}}(t)\right] \cdot \sin(2\pi f_{L1} t) \tag{1}$$

Note that for GIOVE-A the L1-B channel has no sub-carrier. The $e_{L1\text{-B}}$ and $e_{L1\text{-C}}$ components are given by (2) and (3), and due to such multiplexing scheme, there is always possibility to have zero value (for the in-phase branch) output signal when $e_{L1\text{-B}} = e_{L1\text{-C}}$.

$$e_{L1-B}(t) = \sum_i c_{L1-B} \cdot d_{L1-B} \cdot rect\left(t - iT_{c,L1-B}\right) \tag{2}$$

$$e_{L1-C}(t)=\sum_i c_{L1-C}\cdot rect(t-iT_{c,L1-C})\cdot sign[\sin(2\pi R_{s,L1-C}\cdot t)] \tag{3}$$

The L1 OS signal details, including the spreading codes characteristics, are reported in Table 2.

Table 2. Details for data and pilot channels of GIOVE-A Open-Service signal.

Channel	Subcarrier	Subcarrier rate(R_s)	Ranging Code Chip-Rate	Data rate	Secondary code rate	Primary code length	Secondary code length
L1-B (data)	BOC (1,1)	1.023 MHz	1.023 Mchip/s	250 bps	---	4ms/4092chips	---
L1-C (pilot)	---	---		---	125bps	8ms/8184chips	25chips

Doppler Aiding Algorithms

The computational cost required by the acquisition and tracking process of a GNSS receiver represents a key factor in a High Dynamic (HD) scenario, and can be reduced by providing the receiver with Doppler aiding. The acquisition phase in a GNSS receiver consists in the search, step by step, of an estimate of the Doppler shift and code delay for the incoming signal. The search of the Doppler frequency, which should be performed on a range of ±50 KHz for the HD applications, can be fastened if an external Doppler aiding system is used to restrict the number of Doppler frequencies that have to be analyzed.

A Software tool (implemented creating a MATLAB Graphical User Interface) for the computation of the HD Doppler effect between a LEO satellite and a GPS/Galileo satellite has been developed. Starting from a YUMA-like almanac, the positions and velocities of both LEO and GPS/Galileo satellites are computed, together with the line-of-sight between them. The Doppler frequency shift Δf is then proportional to the projection of the relative velocity on the line-of-sight unit vector, and the proportional coefficient is the ratio f_{L1}/c, where c is the speed of light in vacuum, i.e. 299792458 m/s. The Doppler rate is computed by numerical derivative of the Doppler shift.

Results have been validated comparing them with real trajectory data of a LEO satellite, provided by DLR, in order to assess the maximum error, see Fig. 1. It has been observed that this maximum error is in the order of ±50 Hz.

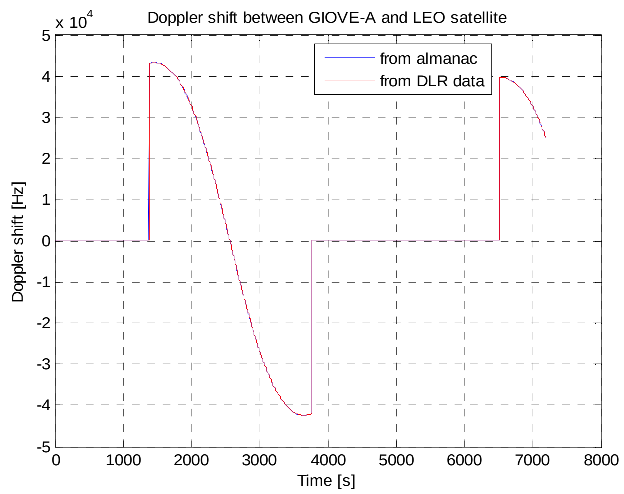

Fig. 1. Comparison plots of- Doppler frequency shift between LEO and GIOVE-A

Signal Acquisition Algorithms

Concerning the Doppler search space, even with such accurate Doppler aiding information, the local oscillator error might be of about ±1.5 kHz [3] and the frequency search-space must be at least 3-kHz wide, centred at the frequency given by the Doppler-aiding estimate. Concerning the code search space, Galileo primary code period for the L1 OS Signal-In-Space (SIS) is 4ms long (4092 chips, or 8184 slots) on data channel and 8ms long (8184 chips, or 16368 slots) on pilot channel. Due to these long code periods and the necessity of small code delay accuracy (better than half a slot), the computational cost required to span all the possible code-delay bins will be greatly higher in the case of Galileo L1 signal with respect to GPS. Some analysis and test results of different acquisition schemes for GIOVE-A signal in high-dynamics environment are given, considering both the warm-start acquisition with Doppler-aiding system and the opportunity of reducing the computational cost of the correlation process. Two main approaches are followed: the use of partial-code correlation and post-correlation FFT.

Partial Correlation Approach

Partial code correlation works by serially correlating a portion of incoming code with its local replica (or vice versa) instead of using a serial search over full code length. The main advantage is the reduction of the computational cost: according to the expression $\Delta f = 2/(3T)$ [1], if a smaller integration time T is used the maximum frequency bin Δf allowed in the search space will be larger. In the following simulations, 1 and 2-ms integration times have been chosen.

Two statistic parameters, which measure the peak-to-noise ratio, are introduced in (4), where R_{PEAK} represents the main peak value of the correlation function and N_{FLOOR} is the global noise floor including the effects of the correlation floor and the noise. These expressions represent the gap between the peak value of the squared correlation function and the max value of the noise floor (α_{MAX}) and the mean value of the noise floor (α_{MEAN}) respectively. Multiple tests have been averaged in the evaluation of α parameters. Because of the extremely low variance of these parameters, in particular of α_{MEAN} (whose variance is about 0.3 dB), 10 tests were considered enough. The α parameters were evaluated only if the 80% of these tests were successful (i.e. the acquisition process reported the correlation peak at the correct code phase and Doppler frequency bin).

$$\alpha_{MAX} = \frac{(R_{PEAK})^2}{\max(N_{FLOOR})^2}, \quad \alpha_{MEAN} = \frac{(R_{PEAK})^2}{mean(N_{FLOOR})^2} \tag{4}$$

Increasing the integration window from 1 to 2 ms the partial correlation performance improves, and for α_{MEAN} it is evident that the performance increases of about 3 dB (Fig. 2), coherently with the fact that the correlation is twice longer in the second case. It has also been noted that correlation results over pilot channel are slightly better than the correlation results over data channel. This might be due to the cross correlation properties of the pilot code, which is longer than the data code.

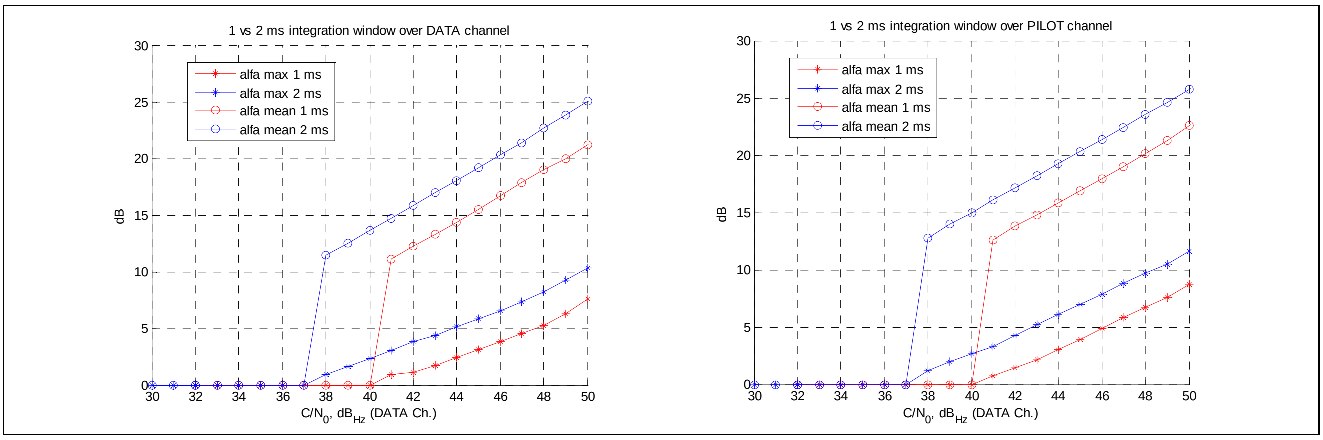

Fig. 2. Peak-to-noise ratio (in dB) for different values of C/N0 – Partial Correlation Approach.

Since this method serially correlates the incoming code and the local replica in both Doppler frequency and code delay domain, a high computation time is expected.

Hybrid FFT Approach

A modification of the partial correlation technique, by introducing a parallel correlation in the frequency domain, has been analyzed, with the objective to reduce the time needed to perform correlation over the whole search-space. A preliminary theoretical study on the computation of the Cross-Ambiguity Function (CAF) has been carried out both to exploit the Doppler aiding information from the trajectory prediction and to reduce the computational effort required by the correlation process. Basically, the CAF envelope S over the k[th] row of the frequency search-space is computed at each sampling instant n by multiplying a snapshot of the incoming signal, as long as the chosen integration window T_{int} (N samples), by the local code replica and taking the spectrum of their product:

$$S^2(n,k) = \left| \frac{1}{N} FFT\{\text{signal snapshot} \times \text{local code}\} \right|^2 \quad (5)$$

By using the FFT the frequency search-space can be computed in a very efficient way with a frequency resolution given by $\Delta f = f_s/N = 1/T_{int}$, where f_s is the sampling frequency. A reduction of complexity is obtained by reducing the sampling rate before the FFT, using a properly designed *decimation* factor. Such a lower sampling rate does not impact the frequency resolution, but reduces the frequency search-space and hence the number of frequency bins. Before down-sampling, the signal must be *down-converted* to a low-frequency band so that decimation can be performed without spectral aliasing. The Doppler-aiding information is used to steer such down-conversion. The residual carrier frequency is then on the order of the Doppler-aiding accuracy (±50 Hz). After the down-conversion, an Integrate and Dump filter is used to perform the desired decimation. Moreover, the use of FFT introduces losses due to its spectral sampling and to the fixed relationship between the frequency resolution and the integration time. *Zero-padding* is used to partially recover such losses.

The resulting reference acquisition scheme is shown in Fig. 3, and the corresponding results are reported in Fig. 4. With the hybrid FFT correlator, no significant difference of performance has been revealed between data and pilot channels, probably due to the cancellation of the incoming code by the local code, without affecting the FFT output.

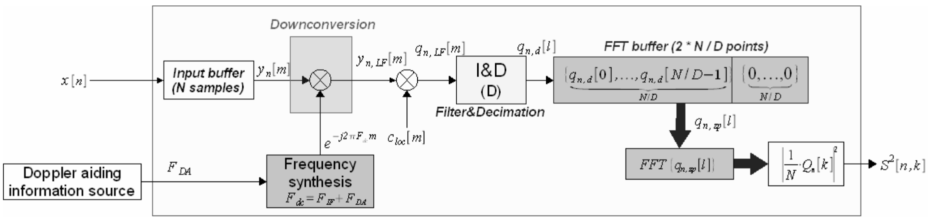

Fig. 3. Reference scheme of the Hybrid FFT correlator.

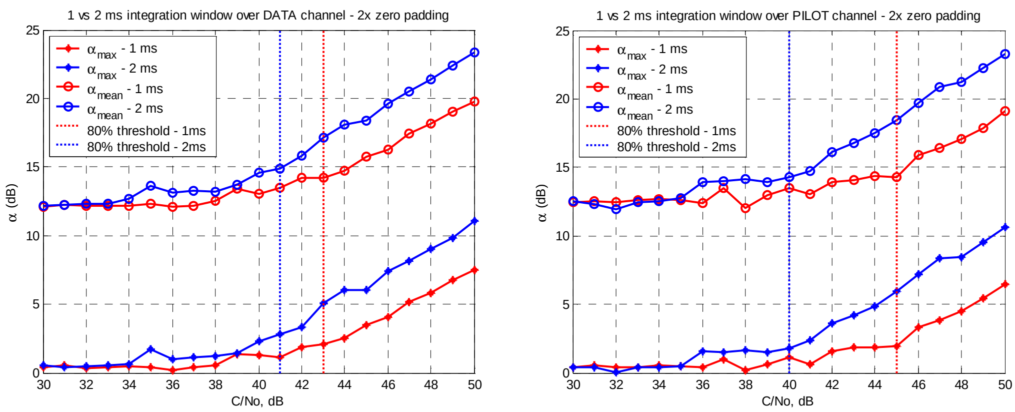

Fig. 4. Peak-to-noise ratio (in dB) for different values of C/N0 – Hybrid FFT Approach.

The average time required to correlate over a whole search-space has been measured. The integration window is the most significant parameter to impact the algorithm complexity. Table 3 shows a comparison between the FFT and the serial approaches on the basis of such parameter. The number of frequency bins is suitable to cover the uncertainty on the local oscillator frequency (±1.5 kHz) plus the Doppler-aiding estimation accuracy (±50 Hz). The frequency-domain approach is the fastest.

Table 3. Average correlation time using Matlab code (on 3.0GHz AMD Athlon 64 X2 CPU)

Channel	T_{int}	Frequency-domain parallel correlation		Partial-code serial correlation	
		No zero-padding	2x Zero-padding	Single frequency bin	search-space (14 bins)
Data	2 ms	156 s	180 s	45 s	630 s
Pilot	2 ms	355 s	449 s	90 s	1260 s

Signal Tracking Algorithms

The signal tracking is on the basis of the overall receiver's processing and allows for estimating the pseudorange (and thus the user's position) and decoding the navigation message. The tracking stage can be considered a two-dimensional (code and carrier) signal replication process. The signal at the output of the IF section is generally processed by a coupled loop composed by a Phase Lock Loop (PLL) or a Frequency Lock Loop (FLL), and a Delay Lock Loop (DLL). Fig. 5 (left) shows the general tracking architecture implemented in any GNSS receivers.

The analysis of the tracking structures for HD signals foresees a second order FLL and an aided first order DLL. The code discrimination function implemented in the simulated architecture is a normalized Non-coherent Early-minus-Late Power. The code tracking loop uses the frequency Doppler estimation performed by the FLL to steer the local code rate. The input for the carrier aiding is simply the carrier tracking loops estimate of Doppler (in Hz at L1) divided by the ratio of the carrier frequency to the code chipping rate. The Doppler aiding implementation in the feedback branch of the DLL is depicted in Fig. 5 (right).

The most important simulation results are shown here after. The Doppler profile used in the signal generation is similar to the one shown in Fig. 1. Two cases were considered in the study, which refer to two different points of such a Doppler profile: maximum Doppler shift and maximum Doppler rate. The case presented in this paper corresponds to the maximum slope of the Doppler profile: Doppler shift equal to 32 Hz, Doppler rate equal to –75 Hz/s.

Both the FLL and DLL perform the tracking on the data channel and use an integration time equal to the primary spreading code period, which is equal to 4 ms. In order to keep the synchronization to the HD input signal using a higher integration time (i.e.: the loop feedbacks only once every 4 ms and not every milliseconds), the equivalent loop bandwidths have been increased to 30 Hz for the FLL and 5 Hz for the DLL. In the following example the initial conditions of the tracking phase assume a code alignment within ±0.5 chips and a frequency error within ±50 Hz.

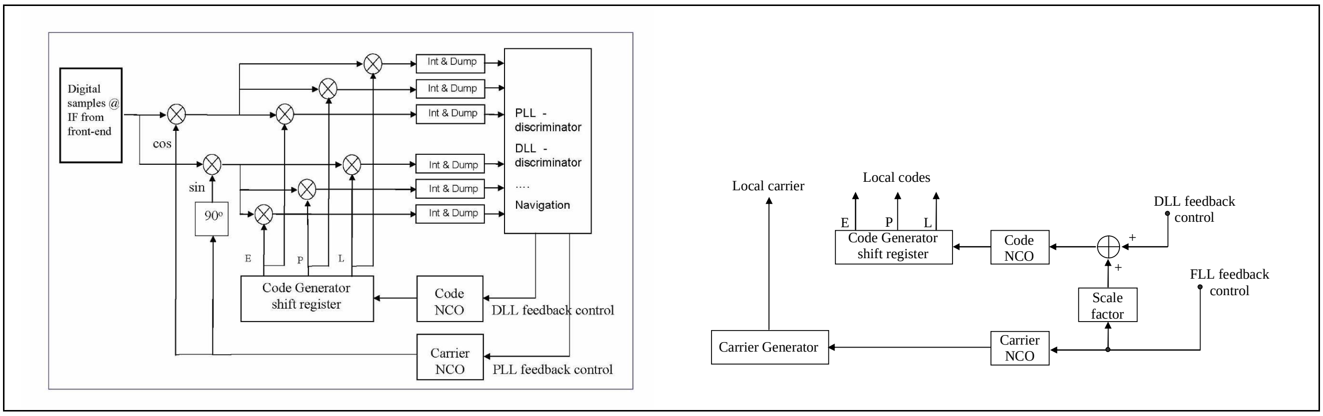

Fig. 5. Tracking systems usually implemented in GNSS receivers (left) and aided first order DLL (right).

The carrier tracking performance can be evaluated considering the difference between the frequency of the local carrier and the frequency of the signal at the output of the IF stage. Using a FLL bandwidth equal to 30 Hz, with a Doppler rate of -75 Hz/s, the frequency of the residual carrier after the carrier wipe-off is slightly higher (12 Hz) and is kept quite constant over 5 seconds of data (see Fig. 6, left). The frequency bias on the carrier tracking can be reduced using a larger FLL bandwidth. If a 50-Hz FLL bandwidth is used, the constant error on the frequency estimation decreases to 4 Hz. Of course, the jitter on the carrier frequency estimation is higher (see Fig. 6, right).

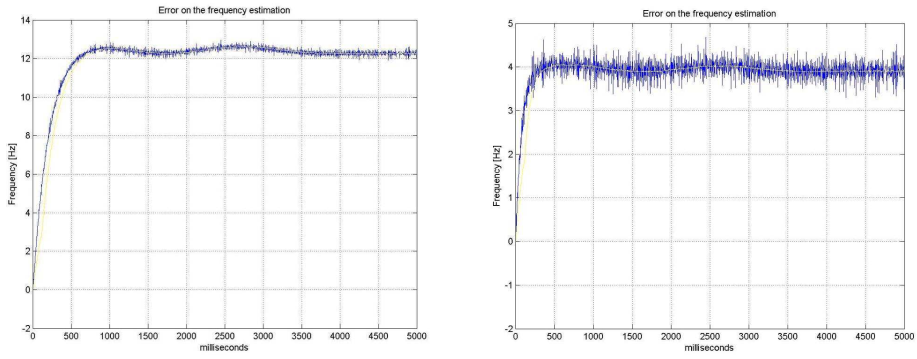

Fig. 6. Error on the carrier frequency estimation using FLL bandwidth of 30Hz (left) and 50 Hz (right).

The pseudorange error as derived from the DLL discriminator output is shown in Fig. 7. As a matter of fact, this result shows that the mean of the pseudorange error is zero, and the standard deviations are showing the jitter in the pseudorange estimation.

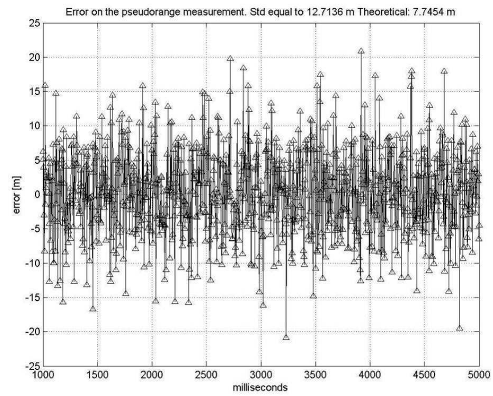

Fig. 7. Error on the pseudorange estimation.

SINGLE-CHANNEL SW RECEIVER

The acquisition and tracking algorithms developed during this study will be implemented using the APIs of the NordNav R30 R&D SW Receiver, equipped with Galileo Extension. This Receiver is a commercial tool for research and development, consisting of an antenna, an RF front-end with an USB connection, and a GPS SW Receiver running on a PC. The tool can be used to collect raw IF samples at the output of the RF front-end (after the A-to-D converter), and to process them in a SW fashion, with an extreme level of flexibility in the configuration of the channels. Moreover, APIs are provided, allowing the deep customization of the signal processing and navigation algorithms. The interfaces are clean enough to allow implementation of virtually any algorithm in the acquisition and tracking domain. The implementation of the GREHDA high dynamic algorithms within this SW Receiver will require the conversion of the analysis scripts (mainly based on Matlab) into C/C++ code, to be integrated in the API framework.

The validation activities will characterize the typical signal processing performances, such as acquisition and tracking thresholds, time to acquire and the accuracy of the raw observables. They will rely on raw IF data streams generated both by the SW Signal Generator, modified to handle high dynamic scenarios, as well as by the Galileo RF constellation simulator available at the ESTEC Navigation Laboratory. The scenarios will represent three LEO trajectories (equatorial, mid-inclination and polar orbits and three different altitudes) and two sounding rockets flights (single-stage and dual-stage rockets), encompassing the most common operating modes of the final receiver.

PRELIMINARY DESIGN OF A SOFTWARE-DEFINED-RADIO GALILEO RECEIVER FOR SPACE APPLICATIONS

When the first results of the algorithms study were available, the preliminary architectural design of a Software-Defined-Radio Galileo receiver could start. This receiver will be based on a FPGA/DSP board, and the main objective is the correct partitioning of the receiver functions between these two domains: some of the functions will be implemented in hardware, and synthesized on the FPGA, while some other will be executed by high-level software running on the DSP. However, the whole design process will be software-defined: the functions to be implemented on the FPGA will be described using a high-level language such as VHDL, and the software to be executed on the DSP will be coded in a high-level language such as C or C++. This is the reason why the correct HW/SW partitioning is a key task for the final receiver implementation. The architectural design will also include the other aspects of the receiver, such as the RF section, the clock and timing module, the power supply management, the external data interfaces and peripherals. All the design process will be supported by justification coming from the algorithms study.

DEFINITION OF A FLIGHT TECHNOLOGY VALIDATION EXPERIMENT

Finally, a flight technology validation mission will be identified. It will allow testing of the simulated algorithms validity and robustness in the real environment. A suitable LEO mission for validating the concept should have the capability, in terms of volume, mass and power, to board both GREHDA and a GPS receiver for performance comparison, it shall have near-zenith pointing attitude for at least one half of the orbit, and it shall provide the necessary downlink capability for storing and downloading the acquired data from both receivers. It shall also be time-compatible in terms of launch date and operation duration.

CONCLUSIONS

The GREHDA project is currently approaching the end of the Implementation Phase. The basic acquisition and tracking algorithms for high dynamic signals have been studied and validated. The acquisition strategy is based on a hybrid FFT approach, which uses a partial correlation technique and a Doppler aiding to restrict the number of frequency bins to be searched. The tracking structure encompasses a second order FLL coupled with an aided first order DLL.

These algorithms are currently being incorporated into the NordNav R30 APIs, and the first results of the Validation activities will be available in short term. The Transfer Phase, supposed to end in April 2007, will complete the project, meeting all its objectives and constituting the basis for further developments in the field of hybrid GPS/Galileo receivers for high dynamic applications.

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