Fast Acquisition Unit for GPS/GALILEO Receivers in Space Environment

Vincent Calmettes, *Université de Toulouse, ISAE ,TESA, France*
Arnaud Dion, *Université de Toulouse, ISAE ,TESA, France*
Emmanuel Boutillon, *UBS/LESTER, France*
Emmanuel Liegeon, *Thales Alenia Space, France*

BIOGRAPHY

Vincent Calmettes received a Ph.D. degree in signal processing from SUPAERO (ISAE), Toulouse, France.
He is an engineer researcher in the laboratory of signals, communications, antenna and navigation, at ISAE. His research interests include the development of solutions based on DSP and programmable logic devices or ASICs for applications in Digital communications and Signal processing. He is currently working on new Galileo signal processing and GNSS receiver architectures. He is also involved in several projects devoted to positioning and attitude determination, including low cost MEMS sensors characterization and INS/GPS integration.

Arnaud Dion has worked as a development engineer in a small company where he conducted projects based on FPGA. While working, he graduated from CNAM (French engineering school) in 2005. In October 2004, he joined ISAE (French Engineering school on Aeronautics and Space) as a project manager. His projects include electronic architecture design for a UAV (Unmanned Aerial Vehicle), FPGA and ASIC development. He is also involved in research activities in the frame of a Ph.D.

Emmanuel Boutillon received the Engineering Diploma from the Ecole Nationale Supérieure des Télécommunications (ENST), Paris, France in 1990. In 1991, he worked as an assistant professor in the Ecole Multinationale Supérieure des Télécommunications in Africa (Dakar). In 1992, he joined ENST as a research engineer where he conducted research in the field of VLSI for digital communications. While working as an engineer, he obtained his Ph.D in 1995 from ENST. In 1998, he spent a sabbatical year at the University of Toronto, Ontario, Canada. In 2000, he joined the laboratory LESTER (Université de Bretagne Sud, Lorient, France) as a professor. His current research interests are on the interactions between algorithm and architecture in the field of wireless communications.

Emmanuel Liegeon is graduated from the "Ecole Nationale Supérieure d'Electrotechnique, d'Electronique, d'informatique, d'Hydraulique et des Télécommunications". He works at Thales Alenia Space as deputy manager of the ASIC/FPGA design group. He is in charge of the development of multi million gates digital Integrated Circuits, targeted on Deep Submicron Technologies, for space applications. He is particularly involved in setting and improvement of design methodologies to address these challenges.

ABSTRACT

In contrast with ground applications the GNSS constellations are not optimized for space applications. Moreover, the different types of mission, i.e. Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Geosynchronous Earth Orbit (GEO), have all specific requirements. Our motivation is to define an «Ubiquitous GNSS receiver (UGNSS)», i.e. a single receiver able to cope with all types of mission. The analyze of the different types of mission shows that the UGNSS receiver should deal with both GPS and GALILEO signals as well as other future GNSS systems. It should also be able to have fast synchronization and robust tracking with extremely wide Doppler range (LEO mission) or be able to cope with very weak signals (GEO mission).

In order to fulfill those requirements, we define the specifications of a reconfigurable decoder that allows to allocate the hardware resources to the type of processing required by the mission. In this paper we consider the algorithm which aims to acquire GNSS signals. This algorithm is based on two IP cores which perform a 8 points FFT and a 2048 points FFT. These two cores are configured to achieve GNSS signal acquisition in any space mission, by taking into account the signal structure (BPSK(1) or BOC(1,1)) and the signal features (C/No ratio, Doppler span and Doppler rate).

I- INTRODUCTION

In contrast with ground applications, GNSS constellations are not optimized for space applications. Moreover, the different types of mission, i.e. Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Geosynchronous Earth Orbit (GEO), have all specific requirements. Our motivation in this paper is to define an «Ubiquitous GNSS receiver (UGNSS)», i.e. a single receiver able to cope with all types of mission. In order to reduce the cost of the UGNSS receiver and to give him some flexibility, the receiver should adapt its hardware computation resources to the type of signal. This can be done using "coarse grain reconfigurable hardware". This paper presents the preliminary results in the route toward this UGNSS receiver. It concerns the analyze of the requirement in the different type of mission and the definition of a synchronization algorithm.

In this study, only GNSS L1 signals are considered. A system designed for acquiring GPS L1 C/A BPSK(1) signal and the future Galileo E1 OS CBOC(6,1,1/11) signal in any missions is described. This unit will be suitable to LEO missions, taking into account the high dynamic of LEO spacecraft as well as GEO mission considering the poor value of the C/No ratio. The architecture of the receiver will be based on blocks which enable to perform dynamic reconfiguration. Thus the configuration will be adapted to the mission by tacking into account the frequency range and to the C/No ratio, to the GNSS constellation (GPS or Galileo) by considering the signal structure. This unit will allow fast acquisition of the GPS and GALILEO satellites in order to increase the duration of Satellites visibility passes and to limit the effects of high Doppler in LEO mission.

In order to reduce the complexity and the acquisition delay, methods based on FFT, which exploit the code periodicity, are computationally attractive and preferred to a bank of correlators. Two FFT are cascaded to explore simultaneously the time and frequency domains [5],[6]. The sizes of these two Fourier Transforms depend on signals and missions: the frequency range is adapted to the mission whereas the time domain is adapted to the pseudo-period of the signal spreading sequence. One of the novelty of this paper is related to the coherent correlation process which is performed by the use of two Intellectual Property cores designed for 8 points and 2048 points FFT. This correlator will be configured depending on the mission and on the constellation.

Due to data modulation of the GPS signal, the coherent integration time is fixed to 8 ms and the half data bit method described in [10] is used for this constellation. Galileo will provide a Pilot channel which avoids to implement this technique. The configuration concerns mainly the use of the FFT cores. The number of FFT transforms performed over the integration time will depend on the Doppler rate, the C/No threshold and the spreading sequence structure which characterize the incoming signal.

The rest of the paper is divided in 6 sections. First we propose a review of the constraints to be considered for a GNSS space receiver design. This study focuses on constraints related to LEO and GEO missions and allows to compute Doppler ranges and C/No thresholds for any missions. Moreover the impact of new constellations such as the Galileo constellation is analyzed. In the third section the GNSS L1 signals are studied. The structure of the BPSK(1) signal and CBOC(6, 1, 1/11) are compared. Taking into account the properties of these signals the acquisition methods are analyzed for each mission in the section IV. Then an acquisition algorithm based on a processing presented in [6] is studied and adapted here to take into account signals and mission specificities. Finally the complexity of this algorithm is evaluated in the section VI, in term of computational load, depending on the mission.

II- GNSS SPACE RECEIVER SPECIFICITY

Space applications can be divided into 3 categories: LEO which works mainly between 300 and 1000 kilometers above the ground, GEO located at around 36000 and kilometers and Medium Earth Orbit (MEO). In this section, we first describe the LEO application and then, the GEO application.. Highly elliptical orbit (HEO) can be omitted since it combines LEO and GEO aspects in one mission.

II-1 LEO requirement

Autonomous positioning system for satellite using GNSS constellation is a particular application of the navigation. The LEO receivers have a better visibility of GNSS constellation than terrestrial receiver because there is no masking due to obstacles and no troposphere to cross. Moreover, the perturbation of the ionosphere is also significantly reduced. The main constraints of LEO applications is the very high speed of the satellite above the earth: a rotation every 90 mn in average (or 7.7 $km.s^{-1}$ at an altitude of 300 km). This high velocity has two effects. First, both the span of the Doppler effect (±42kHz) and the Doppler rate (±62 $Hz.s^{-1}$) are very large compared to ground application [1]. Second, the time of pass of a GNSS satellite over a LEO satellite is very short, around 20-50 minutes. Since the time duration of the navigation message is 12.5 mn, the time of acquisition should be reasonably short, especially for a cold start.

Finally, as the number of visible satellites is not a problem for LEO application, an acquisition threshold of 42 dBHz ensures the reception of a sufficient number of

GNSS satellite to obtain a good quality of the Geometric Dilution of Precision (GDOP).

II-2 GEO requirement

For GEO applications the Doppler span is ± 8KHz and the Doppler rate is ±1 $Hz.s^{-1}$ [1]. Thus the most significant constraints are the sparse nature of GNSS signals as well as their low received power. The geostationary satellites are above the GNSS constellations and the receiving zone is dramatically reduced. In fact, only GNSS satellites at the opposite side of the earth broadcast a GNSS signal in the direction of the GEO satellite (see Figure 1).

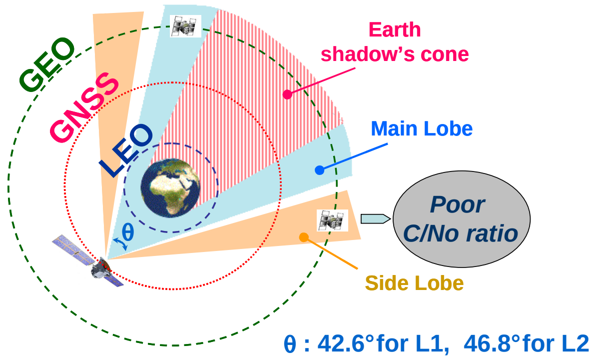

Fig.1-Geometry for reception of GNSS signals by a GEO spacecraft

The number of visible satellites, and then the ability to compute a point solution, is directly linked to the acquisition and tracking C/N0 thresholds. So the first step is to choose thresholds compatible with the expected performances of the receiver in term of precision of positioning, complexity of implementation, etc. Here, the Geometric Dilution of Precision (GDOP) illustrates the precision performances. This parameter gives a good view of the possible performances and it is a purely geometrical factor. The number of visible satellites used to compute the GDOP depends on the acquisition C/N0 threshold T_a and tracking C/N0 thresholds T_t. In the following, the tracking threshold is supposed to be 2 dBHz lower than the acquisition threshold. Thus duration of a visibility pass can be determined. Figure 2 shows the GDOP computed for Telecom2D, as a function of the acquisition and tracking thresholds. The two constellations GPS and Galileo are considered here. The key value for the acquisition threshold is 30 dBHz. For a higher threshold, the GDOP can be very bad (>100), and for a lower one, the gain is not really significant.

The continuity of service, i.e. the time during which it is possible to compute a position solution, is also a key factor for positioning satellites. The passes duration should also be considered. If the time of the GNSS satellite pass is too short, the navigation message can't be completely demodulated. Assuming T_a = 30 dBHz and T_t = 28 dBHz, for GEO applications, most of the passes are between 40-60 minutes in duration, which is sufficient to acquire the 12.5 minutes navigation message.
In that case, the continuity of service is 47.91h over a 48h period for Telecom2D, which is above 99.7 %.

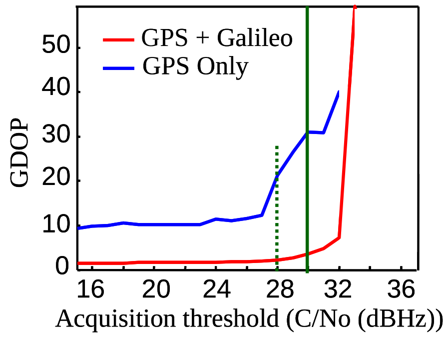

Fig.2-GDOP defined for telecom2D, GDOP provided 95% of the time

II-3 Requirement summary

For the 2 scenarii, LEO and GEO, most of the passes are only 20-60 minutes long, which requires a fast acquisition strategy especially for cold start, in order to maximize the time of the tracking phase.

The table 1 summarizes the requirement of the UGNSS for GEO, LEO mission.. Those parameters will be considered over this study to design the acquisition unit.

Mission type	Doppler range	Doppler rate	T_a (dBHz)	Time of acquisition
GEO	16 KHz	±1 $Hz.s^{-1}$	30	<1mn
LEO	84 KHz	±62 $Hz.s^{-1}$	42	< 0.2sec

Tab.1-Acquisition unit specifications

III- GNSS-L1 SIGNALS

The receiver is designed in order to process the GPS-L1 C/A signal as well as the Galileo-L1 OS signal. Both GLS-L1 and GALILEO-L1 signals are described in this section. These signals are sampled at the frequency $F_s = 1/T_s$. The GPS-L1 signal is a BPSK(1) signal whereas the Galileo-L1 signal is a CBOC(6, 1, 1/11) signal. In this paper this signal is processed as a BOC(1,1) signal.

The complex signal is considered as the input of the acquisition unit. For both signals the expression is the following :

$$s_n = \sqrt{C} D(n-\tau_n) S_e(n-\tau_n) e^{j\varphi_n} + n_n \quad (1)$$

τ_n is the time delay due to the propagation of the signal
C is the power of the signal
D is the data signal
S_e is the spreading signal
φ_n is the carrier phasis
n_n is an additive Gaussian white noise

III-1 GPS L1 signal

When the GPS L1 signal is considered the data rate of the data signal D is 50 bps. Each data value multiplies 20 periods of the spreading sequence. This spreading sequence S_e , as defined in (1), is a pseudo-random code of period 1023 chips, based on a Gold code C_G :

$$S_e(n) = C_G(n) \qquad (2)$$

The chip rate f_c $=1/T_c$ is equal to 1.023MHz and the pseudo period of the spreading signal is 1ms.

III-2 Galileo L1 signal

The Galileo-L1 signal has been designed in order to offer a high degree of spectral separation from GPS-L1 signal. A Binary Offset Carrier (BOC) modulation is performed. Thus, each chip of the code sequence is over modulated by a pattern {+1, -1}. The expression of the spreading signal S_e is the following :

$$S_e(n) = C(n)sign(\sin(2\pi f_{sc} n)) = C(n)sc_s(n) \qquad (3)$$

The modulating sequence is represented by a pseudo-random $C(n)$ code mixed with a square sub-carrier sc_s. The modulation is a BOC(1,1) modulation. Thus the chip rate f_c ($=1/T_c$) is equal to 1.023 chips per second and the sub-carrier frequency f_{sc} ($=1/T_{sc}$) is equal to 1.023MHz. The code length is 4092 and the pseudo period is equal to 4ms. The data rate is 250 bps; thus each data value multiplies a single pseudo period of the spreading sequence. Moreover a pilot channel is provided.

III-3 Comparison between GPS-GALILEO L1 signals.

The power spectral density (PSD) is represented Figure 3 for a BPSK(1) signal and a BOC(1,1) signal. This Figure shows the spectral separation from GPS signal.

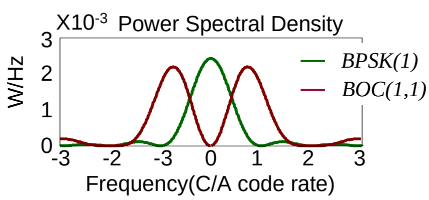

Fig.3-PSD for BOC(1,1) and BPSK(1) signals

The signal's processing performance in the receiver stage is strongly linked to the Auto Correlation Function (ACF) shape. For the BOC(1,1) modulation, the ACF function presents one positive peak and two negative peaks. This function is represented Figure 4 for a BPSK(1) signal and a BOC(1,1) signal.

Those ACF functions impact the acquisition and tracking process of the signal.

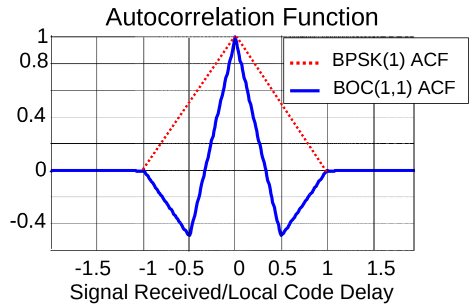

Fig.4- ACF for BOC(1,1) and BPSK(1) signals

III-4 Signals sampling

The sampling frequency is determined from the signal bandwidth (see Figure 3). It is chosen as equal to the Spectrum bandwidth.

$Fs = 1/Ts \sim 2.048MHz$ for GPS-L1 signal
$Fs = 1/Ts \sim 4.096MHz$ for Galileo-L1 signal

IV- ACQUISITION PRINCIPLE

The expression of the signal at the receiver input is given in (1):

$$s_n = \sqrt{C}D(n-\tau_n)S_e(n-\tau_n)\exp\{j\varphi_n\} + n_n$$

Where S_e is the spreading signal defined in (2) or (3), depending on the signal structure.

Assuming the signal is propagated through a non dispersive medium and considering the satellite-receiver radial velocity as constant, the phase of the signal is deduced from the Doppler frequency f_d.

$$\varphi_n - \varphi_{n-1} = 2\pi f_d T_s \Rightarrow \varphi_n = \varphi_0 + 2\pi f_d n T_s \qquad (4)$$

And the signal expression is:

$$s_n = \sqrt{C}D(n-\tau_n)S_e(n-\tau_n)\exp\{j(\varphi_0 + 2\pi f_d n T_s)\} + n_n \qquad (5)$$

The purpose of the acquisition is to find a good estimation $\{\hat{f}_d, \hat{\tau}\}$ of the unknown value of the pair $\{f_d, \tau\}$. An hypothesis test is defined. The statistic test generated by the samples s_n is defined Figure 5. The output Z_l is compared to a threshold. The statistic test exploits the ACF properties. The correlator output is computed in two stages: a coherent integration followed by a non-coherent integration. The number of samples used for this test is equal $N_1N_2N_3$. N_1 is the number of samples over one period of the spreading signal. N_2 is the number of spreading sequence over the coherent integration time. N_3 is the number of non coherent integrations.

The architecture of the correlator is represented Figure 5.

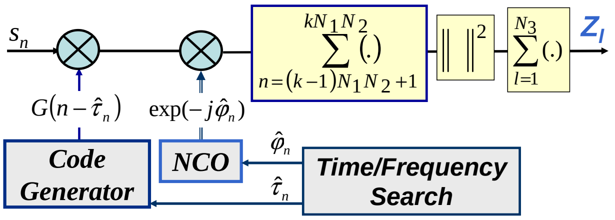

Fig.5-Structure of the Acquisition stage

N_1 T_s, which represents the pseudo period, is equal to 1ms for a Gold GPS-C/A code, 4ms for the L1-OS-Galileo code).

The representation of the output Z_l depends on the properties of the autocorrelation function (ACF) of the spreading sequence. For GPS signal the ACF has a single peak over a pseudo period and this characteristic is exploited to find the estimate of the delay τ. When the Galileo BOC signal is considered, this acquisition process is made more complex. The BOC ACF has multiple peaks and the risk of wrong peak selection should be considered (see Figure 4). In order to resolve this ambiguity problem, the BOC signal is acquired along three steps [8] (see Figure 6).

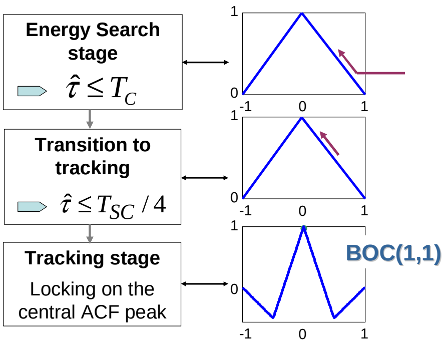

Fig.6-Acquisition strategy

First a coarse acquisition is performed by searching the code delay which provides an expected level of energy. This step needs non ambiguous techniques. The next step uses a tracking loop based on a non ambiguous discriminator and provides an unbiased delay estimation. Finally the receiver is turned in a nominal BOC tracking mode. The discriminator used in this mode allows accuracy improvement and multipath rejection enhancement.

Several non ambiguous techniques have been developed to be used along the two first steps. Among them are the “BPSK-like” correlation [2], the Sub-Carrier Phase Cancellation technique (SCPC) [3], the Bump-Jumping technique [4] and techniques based on the Teager Kaiser Operator [9].

Here the SCPC technique, which processes the sub-carrier as it is done for the carrier in a typical receiver, is used to acquire the Galileo BOC(1,1) signal. The architecture of the acquisition stage based on the SCPC technique is represented Figure 7. This technique needs two correlation channels [3]. The I channel uses the spreading code mixed with the in-phase sub-carrier as a reference. The Q channel uses the spreading code mixed with the quadra-phase sub-carrier as a reference. The outputs of this two correlation channels are non-coherently combined.

The correlator used in the SCPC technique is represented here.

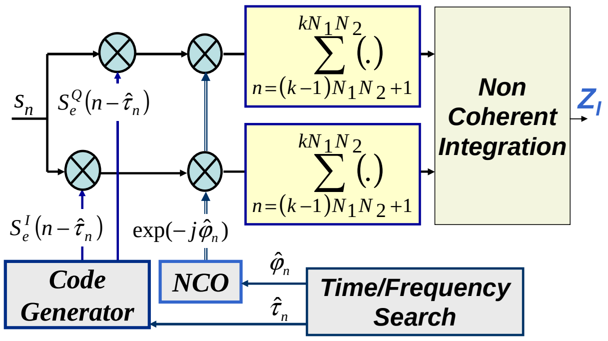

Fig.7-Unambiguous SCPC technique

On this figure, the local references have the following expression:

$$\begin{aligned} S_e^I(n) &= C(n)sign(\sin(2\pi f_{sc} n)) = C(n)sc_s(n) \\ S_e^Q(n) &= -C(n)sign(\cos(2\pi f_{sc} n)) = C(n)sc_c(n) \end{aligned} \quad (6)$$

The ACF is represented on the Figure 8. This autocorrelation has an oscillating shape which presents a maximum when the local sequences are time-aligned with the received signal.

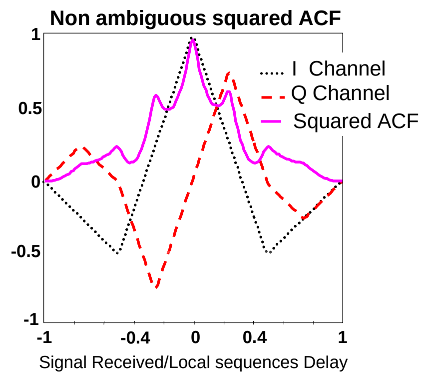

Fig.8-Non ambiguous ACF

Thus, GPS C/A BPSK(1) signal and Galileo OS BOC(1,1) signal are acquired by searching the estimate of the pair $\{\hat{f}_d, \hat{\tau}\}$. This estimate is selected if the output

$Z_l(\hat{f}_d, \hat{\tau})$, provided by a correlator, is higher than the threshold assigned for the statistic test. The architecture of this correlator depends on the signal structure. For a BPSK(1) signal it is based on a single correlation channel (see Figure5) whereas the SCPC technique used for BOC(1,1) acquisition needs two correlation channels. This correlator performs a coherent integration following by a non-coherent processing. In this application the coherent integration time is 8 ms (i.e. $N_2=8$ for GPS, $N_2=2$ for Galileo). It is adapted to the data rate of the GPS L1 signal. To avoid data bit transition over the summation interval the half data bit method [10] is applied.

V- ACQUISITION ALGORITHM

In a conventional receiver the search of the optimum value of the estimate $\{\hat{f}_d, \hat{\tau}\}$ is performed in time domain.

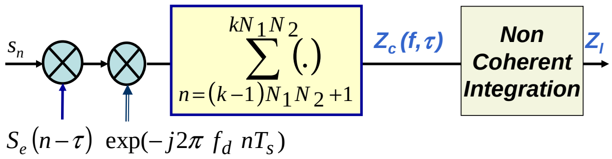

Fig.9-Correlator in time domain

The function test is described Figure 9. The search is performed through the space $\{f_d, \tau\}$. This processing is time consuming. The complexity depends on the size of the array $\{f_d, \tau\}$ and on the number of non-coherent integrations.

First, the size of the array $\{f_d, \tau\}$ is related to the mission. The size of the frequency range is 84KHz in a LEO mission, whereas it is 16KHz for a GEO mission. Then this size depends on the signal structure. The GPS C/A code is a code of length 1023 chips whereas the Galileo OS code is a code of length 4092.

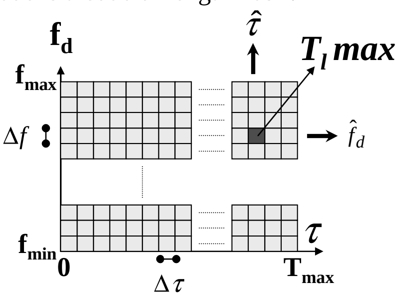

Fig.10-Search Array

In order to determine the number of non-coherent integrations, the C/No ratio and the structure of the signal should be considered. Here we consider a C/No ratio of 30dBHz for a GEO Mission, of 42dBHz for a LEO mission (see Table 1). The Figures 11 and 12 give the value of the integration time as a function of the C/No ratio, respectively for a BPSK(1) signal and a BOC(1, 1) signal. In case of BOC signal, the SCPC technique is considered. The coherent integration time ($T_{coh}= N_1N_2T_s$) is equal to 8ms and the False Alarm probability is assigned to 10^{-3}. The search is performed with a step $\Delta\tau=1/2f_c$ and $\Delta f=1/2/T_{coh}$. A non-coherent square-law detector is used. The results are obtained for a miss probability of 0.1 and 0.001. A miss probability of 0.1 is considered over the following study.

For a C/No ratio higher than 38dB, the number of non-coherent integrations N_3 is equal to 1. This value of N_3 is chosen in case of LEO mission. For GEO mission, by considering a low Doppler rate, the coherent correlators are differentially combined [7] and a gain of 2dB is achieved. The value of the number N_3 is therefore selected for a C/No ratio of 32dBHz. Then the number of non coherent integrations is equal to 6 when a BPSK(1) signal is considered. It is equal to 7 when a BOC(1,1) signal is processed using the SCPC technique. The highest value of N_3 (N_3=7) is considered here for any signals.

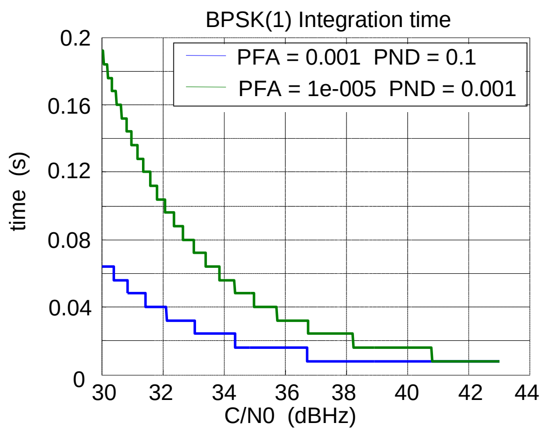

Fig.11-BPSK(1) signal
Integration Time as a function of the ratio C/No

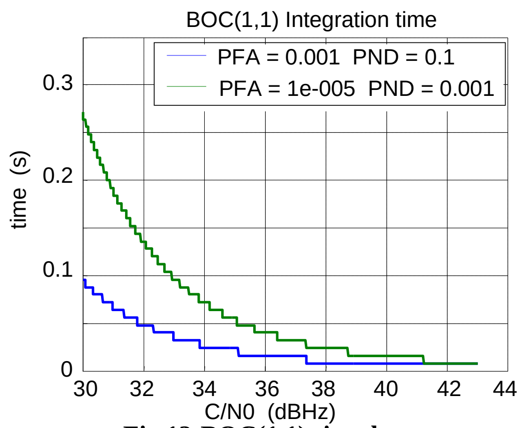

Fig.12-BOC(1,1) signal
Integration Time as a function of the ratio C/No

In order to determine the acquisition time of one satellite, in case of a serial search, the Tables 2, 3, 4 and 5 give the number of coherent integrations N_{it} and the corresponding computing time T_{comp} for any missions and signals. These values are computed by considering a serial search, performed through the whole array $\{f_d, \tau\}$. For GPS signal the half data bit method is used and $2N_3$ coherent integrations are processed. The time and frequency steps are fixed to the following values: $\Delta\tau = 1/2 f_c$, $\Delta f = 1/2T_{coh}$. The expression of N_{it} and T_{comp} are given here:

$$N_{it} = \beta(f_{\max} - f_{\min}) / \Delta f * 2N_{chips} * N_3$$

$$T_{comp} = N_{it} * T_{coh} \text{ for Galileo } T_{comp} = N_{it} * 10mS \text{ for GPS}$$

Where N_{chips} is the code length expressed in chips and T_{coh} is the coherent integration time (8ms).

GEO Mission, GPS/L1, β=2 (half data bit method)				
T_{max}	f_{max} -f_{min}	N_3	N_{it}	T_{comp}
1ms	16KHz	7	7332864	1223 mn

Tab. 2-GEO/GPS-L1

GEO Mission, Galileo/L1, β=1 (Pilot channel)				
T_{max}	f_{max} -f_{min}	N_3	N_{it}	T_{comp}
4ms	16KHz	7	14665728	1956 mn

Tab. 3- GEO/Galileo-L1

LEO Mission, GPS/L1, β=2 (half data bit method)				
T_{max}	f_{max} -f_{min}	N_3	N_{it}	T_{comp}
1ms	84KHz	1	5499648	916 mn

Tab 4- LEO/GPS-L1

LEO Mission, Galileo/L1, β=1 (Pilot channel)				
T_{max}	f_{max} -f_{min}	N_3	N_{it}	T_{comp}
4ms	84KHz	1	10999296	1466 mn

Tab 5- LEO/Galileo-L1

In order to reduce the delay of the acquisition processing a bank of correlators could be used. Techniques based on a bank of correlators allow to explore the whole array $\{f_d, \tau\}$ over the interval of integration (N_3T_{coh}). But such an architecture is highly complex. In practice fast acquisition approaches are based on the Fast Fourier Transform (FFT). These methods lead to reduce the number of arithmetic operations [6]. Thus many designs use a one-dimensional FFT to sweep one dimension of the array $\{f_d, \tau\}$: the time domain or the frequency domain is explored. In this paper we consider an approach based on a technique presented in [6] which allows to estimate both the delay and the Doppler frequency of the input signal. This technique is described here. It is adapted in order to process both BPSK(1) and BOC(1,1) signals.

The expression of the input is given in (5).

$$s_n = \sqrt{C}D(n-\tau_n)S_e(n-\tau_n)\exp\{j(\varphi_0 + 2\pi f_d nT_s)\} + n_n$$

The expression of the coherent correlator output described Figure 9 is:

$$Z_c(\tau, f_d) = \sum_{n=0}^{N_1N_2-1} s_n \exp\{-j2\pi f_d nT_s\} r_{n,\tau} \qquad (7)$$

In this expression, the signal r represents the local reference. For a BPSK(1) signal, r is the pseudo-random sequence. In case of BOC(1,1) signal, r is defined in (6) for the In-Phase channel and for the Quadra-Phase channel.

The correlator output Z_c should be computed for each value of the array described Figure 10. By considering n_1 the position of the sample in a block of size N_1 such as N_1T_s=1ms or 4ms depending on the signal, and n_2 the index of a block, we obtain $n=n_1+n_2 N_1$. The signal is reshaped in an array of size N_1 x N_2 (see Figure 15). Taking into account the spreading sequence periodicity, the output Z_c is:

$$Z_c(\tau, f_d) = \sum_{n_1=0}^{N_1-1} r_{n_1,\tau} \sum_{n_2=0}^{N_2-1} s_{n_1+n_2N_1} \exp\{-j2\pi f_d(n_1+n_2N_1)T_s\} \qquad (8)$$

In [6], the frequency domain is explored in two stages. The first one is a coarse search which allows to sweep the frequency domain with a step which is the inverse of the pseudo period of the spreading sequence. The second one is a fine search equal to Δf which is the inverse of the coherent integration time.

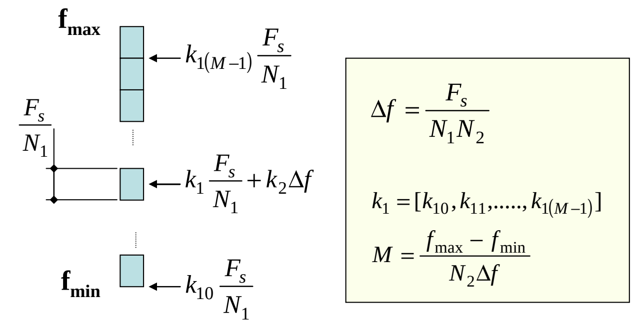

Fig 13- Strategy for the Frequency Domain exploration

The frequency resolution ($1/T_{coh}$) is not adapted to GEO mission, due to the low value of the C/No ratio. The interlacing of two correlations, as described Figure 14, allows to obtain the required resolution ($1/2T_{coh}$).

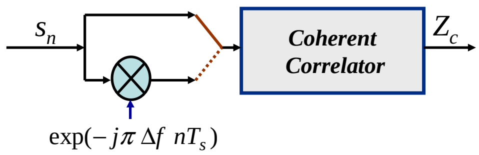

Fig 14- Interlacing of two correlations

Using this technique, the frequency domain is explored with the steps given in the table 6 for any missions and signals.

	BPSK(1)	BOC(1,1)
Coarse Step	1KHz	250Hz
Fine Step	62.5Hz	62.5Hz

Tab 6- Frequency steps

Thus, considering one correlator, the frequency step is:

$$\Delta f = F_s / N_1 / N_2 \qquad (9)$$

And the frequency can be expressed from 2 index k_1 and k_2 [6] as shown Figure 13.

$$f_d = (k_1 N_2 + k_2)\frac{F_s}{N_1 N_2} = k_1 \frac{F_s}{N_1} + k_2 \frac{F_s}{N_1 N_2} \qquad (10)$$

For $k_1=[\, k_{10}, k_{11}, \ldots. k_{1(M-1)}]$ a coarse search is performed over the frequency domain, with a step size which is the inverse of the code pseudo period (F_s / N_1). For $k_2=[0, 1,\ldots, N_2]$ the fine search is performed over the block indexed by k_1. The width of a block is 1KHz for the GPS-L1 signal, 250 Hz for the Galileo-L1 signal.

Using this representation of the frequency the correlator output is given in [6]:

$$Z_c(k_1,k_2,\tau) = \sum_{n_1=0}^{N_1-1} r_{n_1,\tau} \exp\left\{-j2\pi \frac{n_1(k_2+k_1N_2)}{N_1N_2}\right\} T_1(k_1,k_2,n_1) \qquad (11)$$

where:

$$Z_1(k_1,k_2,n_1) = \sum_{n_2=0}^{N_2-1} s_{n_1+n_2N_1} \exp\left\{-j2\pi \frac{n_2k_2}{N_2}\right\}$$

The fine frequency search is performed for $k_2=[0,.. N_2-1]$ by computing the output Z_1 thanks to the well-known FFT algorithm. The samples of the input are organized in a 2-dimensional array and a N_2 points FFT is applied to the N_1 rows of this array (see Figure 15).

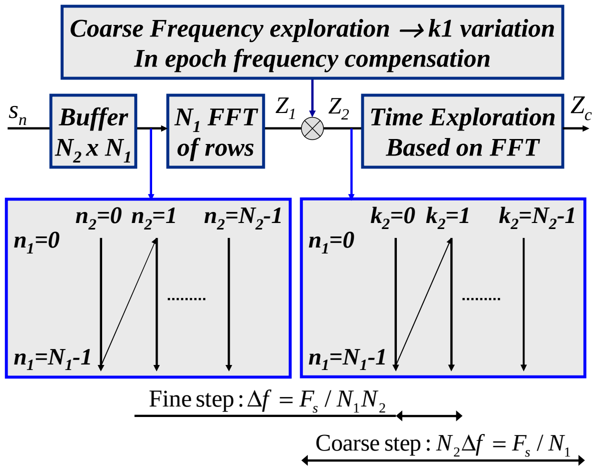

Fig.15- Coherent Correlator Architecture

Then, an element-wise multiplication is applied to the elements of the array Z_1, in order to achieve in-epoch compensation and coarse frequency exploration. Thus the output Z2 is :

$$Z_2 = Z_1 \exp\left\{-j2\pi \frac{n_1k_2}{N_1N_2}\right\} \exp\left\{-j2\pi \frac{n_1k_1}{N_1}\right\}$$

In epoch compensation — Coarse frequency exploration

Coarse frequency exploration will allow to sweep the whole frequency domain by modifying the value of the index k_1.

From the array Z_2, search over the time domain is obtained using a FFT. This transform is noted F{.} and the expression of the output Z_c is:

$$Z_c\{\tau\} = \mathrm{F}^{-1}\{\mathrm{F}\{r\} F\{Z_2\}\}$$

The coherent output Z_c is obtained over several stages:

- a N_1 points FFT to each column of the array Z_2
- N_1N_2 wise element multiplications by the local reference represented in frequency domain
- a N_1 points inverse FFT to each column of the array Z_2

The coherent correlation is obtained over an array of size $T_{max} x N_2 \Delta f$ (see Figure 10 and Figure 13). In order to explore the frequency domain over the range ($f_{min}<f<f_{max}$) this processing should be performed for k_1 in $\lfloor k_{10}, k_{11}, \ldots, k_{1(M-1)} \rfloor$ (see Figure 13).

The Table 7 gives the width of the frequency domain explored for a single value of the index k_1, and the number of iterations M for each signals and missions (BPSK(1) and BOC(1,1)).

GEO Mission			
Signal	T_{max}	$N_2\Delta f$	M
BPSK(1)	1ms	1KHz	16
BOC(1,1)	4ms	250Hz	64
LEO Mission			
Signal	T_{max}	$N_2\Delta f$	M
BPSK(1)	1ms	1KHz	84
BOC(1,1)	4ms	250Hz	336

Tab 7- Time/Frequency Domain exploration

It is shown in [6] that the coarse frequency exploration can be achieved by shifting the spreading sequence replica in the frequency domain. The final architecture is described Figure 16. The coherent correlator is based on 3 FFT blocks: one N_2 points FFT, two N_1 points FFT.

The FFT size N_1 such as N_1T_s represents the pseudo period of the spreading sequence and the FFT size N_2

such as $N_1N_2T_s$ represents the duration of the coherent integration are given Table 8 for the GPS-L1 signal and the Galileo-L1 signal.

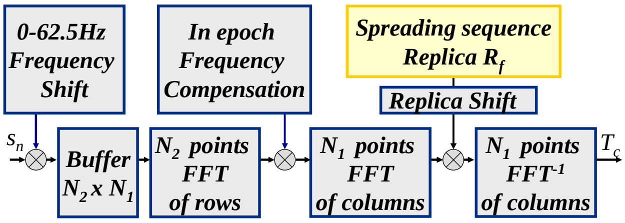

Fig.16-Search in time/frequency domain

Signal	N_1	N_2
BPSK(1)	2048	8
BOC(1,1)	16384	2

Tab 8- Sizes of the FFT

VI- ACQUISITION UNIT ARCHITECTURE

This unit is based on the coherent correlator described Figure 16. It should be configured for LEO mission and GEO mission, for GPS-L1 and Galileo-L1 signal. Two IPs are used in this design: a 8 points FFT and a 2048 points FFT. Thus the 16384 points FFT is performed from 64 FFT of size 2048.

VI-1 Signal Acquisition in LEO Mission

For LEO mission, the acquisition is performed from one set of samples which represents the input signal over a duration of 8ms. When the GPS signal is considered, the Half Data Bit technique described in [10] is used. The acquisition stage should process two sets of samples. The interval between this two steps is T_i such as $T_i = (2k+1)10mS$. The maximum value of the index k is determined from the Doppler rate (±62 $Hz.s^{-1}$). The index k will be lower than 25 in order to limit the Doppler Frequency variation between two acquisition stages. Thus the acquisition time is equal to 518 ms (51*10ms+8ms). The same value can be taken for Galileo.

The computing load is determined for the acquisition of a GPS satellite or a Galileo satellite. Over the interval of 510ms during which the Doppler drift remains lower than 32 Hz, the following operations (see Figure 16) will be performed:

-1 0-62.5Hz Frequency shift
- N_1N_2 point-wise multiplications

-2 N_2 points FFT of rows
- $2N_1$ FFT_{N2}

-3 In epoch frequency compensation
- $2N_1N_2$ point-wise multiplications

-4 N_1 points FFT of columns
- $2\mu N_2$ FFT_{2048}

-5 Replica multiplication
- $2\alpha MN_1N_2$ point-wise multiplications

-6 N_1 points FFT^{-1} of columns
- $2\alpha\mu MN_2$ FFT_{2048}

The coefficient μ depends on the number of 2048 points FFT used to compute N_1 points FFT. It is equal to 1 for a GPS satellite, to 64 for a Galileo satellite.
The coefficient α depends on the structure of the signal. It is equal to 1 for a GPS satellite, to 2 for a Galileo satellite. In this case the In-Phase and the Quadra-phase replica should be considered.
M as given Table 7 for LEO mission.

VI-2 Signal Acquisition in GEO Mission

For GEO mission the acquisition is achieved as it is done for LEO mission. The lower Doppler range leads to a reduction of the complexity. But, due to higher values of the integration time the same processing should be performed N_3 times for Galileo, $2\ N_3$ times for GPS (for GPS the half data bit method is used).

Nevertheless, thanks to the very low dynamic of GEO satellites, discontinuous blocks can be processed. Thus higher value of the acquisition time results in a reduction of the computational load in term of operations per second.

VII- CONCLUSION

This study presents a technique to acquire GNSS-L1 signals, in a receiver designed for space environment. The GPS-L1 C/A signal and the Galileo-L1 OS signal, the LEO mission and the GEO mission are considered.

By taking into account the specificities of the 2 missions, the features of the receiver are deduced. On the other end, algorithms are proposed in order to process GPS and Galileo signals. The architecture of a receiver, based on 2 FFT cores, is described. This architecture can be configured for the two missions and the two signals. This architecture is analyzed in term of complexity and performance (acquisition time). The requirement on the acquisition time impacts the computational load. For LEO mission, due to the high dynamic of the satellite, this acquisition time should be lower than 1 sec. On the contrary GEO application are characterized by low dynamic and the acquisition time can be higher. Increasing the acquisition times results in a lower complexity, and consequently in a lower power consumption.

VIII- REFERENCES

[1] A. Dion, V. Calmettes, E. Boutillon. “Reconfigurable GPS-Galileo receiver for satellite based applications”, *Proceedings of ION GNSS 2007*

[2] Philip M. Fisman,John W. Betz, “Predicting Performance of Direct Acquisition for the M-Code Signal”, *Proceeding of ION NTM 2000*

[3] V. Heiries, D. Roviras, L. Ries, V. Calmettes, “Analysis of Non Ambiguous BOC Acquisition Performance”, *Proceedings of ION GNSS 2004*

[4] P. Fine, W.Wilson, “Tracking Algorithm for GPS Offset Carrier Signals”, *Proceeding of ION 1999*

[5] D. Akopian, “A fast satellite acquisition method”, *Proceeding of ION GNSS 2001*

[6] D. Akopian, “FFT based satellite acquisition methods”, *IEE Proc. Radar, Sonar and navigation, Vol. 152, No 4, August 2005, Pages 277-286*

[7] W. Yu, B. Zheng, R. Watson, G. Lachapelle. “Differential combining for acquiring weak GPS signals”, *Signal Processing, Volume 87, Issue 5 (May 2007), Pages 824-840*

[8] N. Martin, V. Leblond, G.Guillotel V. Heiries, “BOC(x,y) signal Acquisition techniques and Performance”, *Proceedings of ION GNSS 2003*

[9] V. Heiries, C. Rendon, V. Calmettes, “Solving the Correlation Ambiguity Issue of BOC Modulated Signal by a Nonlinear Quadratic Operator”, *Proceedings of ION GNSS 2006*

[10] M. Piaski, “Block acquisition of weak GPS signals in a software receiver”, *ION GPS 2001*