First Results on Acquisition and Tracking of the GIOVE-A Signal-in-Space

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Abstract. This paper presents the first results obtained processing the Signal-In-Space broadcast by the Galileo In – Orbit Validation Element A (GIOVE-A) satellite, the first experimental Galileo satellite. The paper analyzes both the acquisition and tracking phase of a Galileo software receiver able to process raw samples of the signal collected by means of a commercial front end. Starting from the description of the system set up used to collect the data set the paper introduces the Partial Correlation approach adopted in the acquisition phase and describes the tracking structures used to synchronize the local and the incoming codes. Techniques tailored to the new structure of the Galileo signal have been employed. In fact, the GIOVE-A signal uses novel modulation schemes and it is made of longer spreading codes that required modification to both the acquisition and tracking algorithms usually implemented within a GPS receiver.

1 Introduction

On 28th of December 2005 the first Galileo satellite was launched from Baikonur, Kazakhstan. The satellite named GIOVE-A started broadcasting the signal on 12th of January 2006 and the event was definitely a milestone in the development of the new European Global Navigation Satellite System (GNSS).

After the launch, several experiments have been performed from many different sites to monitor the quality of the signal and check the health of the electronic devices on board of the satellite. Due to the low power of the received signal (i.e. the signal power spectral density is approximately 20 dB lower than the thermal noise floor) in all the experiments, a high gain antenna has been used to track the GIOVE-A satellite.

At the beginning of March, the initial results of the analysis performed in Weilheim (Germany) have been published by Montenbruck et al. [1]. Then, on 31st of March, on the basis of the previous work, the GPS group at the Cornell University has been able to decode and publish the Galileo codes on the web [2].

The availability of the codes represented a new opportunity for all the scientists working in the navigation field to test the first Galileo receivers/algorithms with real data sets.

2 GIOVE-A Signal

As it is well described in [1], for the L1 band, the transmission chain on board of GIOVE-A follows the block diagram depicted in Fig. 1.

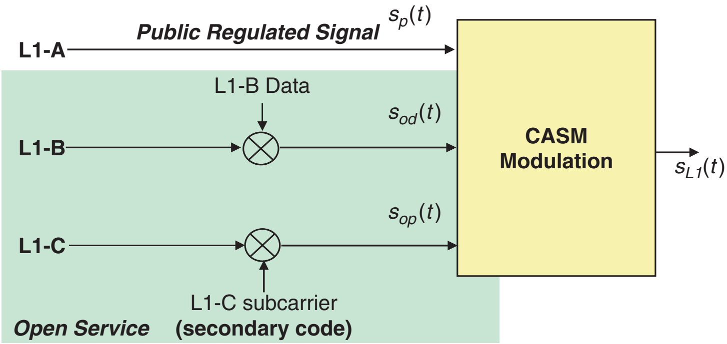

Fig. 1. GIOVE-A signal block diagram.

The Galileo signal modulation has two specific characteristics: filtered Binary Offset Carrier(BOC) pulse form and Coherent Adaptive Subcarrier Modulation (CASM) [3]. The BOC waveform was originally conceived in order to allow a spectral separation between the existing single carrier GPS signals and the new signals. In addition, if properly exploited, the new signals also provide a better performance in multipath environments [4]. To ease the acquisition and tracking under weak signal conditions, Galileo includes a pilot on each carrier. As a consequence, the L1-band accommodate a total of three signals: a pilot $s_{op}(t)$, a data signal $s_{od}(t)$ for the Open Service (OS) and Safety Of Life Service (SOL) and a data signal $s_p(t)$ for the Public Regulated Service (PRS). Priorities and jamming constrains led to the following mapping of signals [5].

$$s_{L1} = \frac{\sqrt{2}}{3}\left[s_{od}(t) - s_{op}(t)\right]\cos(2\pi f_{L1} t) + \frac{1}{3}\left[2s_p(t) + s_{od}(t)s_{op}(t)s_p(t)\right]\sin(2\pi f_{L1} t) \quad (1)$$

with f_{L1} = 1.57542 MHz, and

$$\begin{aligned} s_{od}(t) &= d_{od}(t)c_{od}(t)\,sign(\sin(2\pi f_s t)) \\ s_{op}(t) &= c_{op}(t)\,sign(\sin(2\pi f_s t)) \\ s_p(t) &= d_p(t)c_p(t)\,sign(\cos(30\pi f_s t) \end{aligned} \quad (2)$$

In this expression, f_s denotes the subcarrier frequency of the OS signal which has been selected to match the OS chip rate f_c = 1.023 MHz. The modulated data bits $d(t)$ and code bits $c(t)$ are given by

$$\begin{aligned} d_{od}(t) &= d_m^{(od)}\ if\ mT_b \le t < (m+1)T_b \\ c_{od}(t) &= c_m^{(od)}\ if\ mT_c \le t < (m+1)T_c \\ c_{op}(t) &= d_m^{(op)}\ if\ mT_c \le t < (m+1)T_c \\ c_p(t) &= d_m^{(p)}\ if\ mT_c \le 2.5t < (m+1)T_c \end{aligned} \quad (3)$$

Here $T_c = \frac{1}{f_c} \approx 1\mu s$ and $T_b = 4.902 \cdot T_c = 4ms$ denote the duration of an individual OS code chip and the duration of the entire OS data code sequence, respectively. As mentioned before Galileo include also a Pilot channel which a code sequence longer than the Data channel one. Its duration is 8ms.

3 System Setup

In this Section the experimental system set up used to collect and to post process the real data of GIOVE-A satellite is described.

Figure 2 shows the block diagram of the system set up: the signal is received by an L1 antenna connected to a commercial front-end and recorded on a storage support.

The front-end is based on a Application Specific Integrated Circuit (ASIC) basic front-end with a bandwidth of about 4MHz, an intermediate frequency f_{IF} = 4.1304MHz and a sampling frequency f_s = 16.3676 sample/s and quantized over 4 bits.

The raw data collected have been post processed by means of a software tool able to perform the signal acquisition and tracking. Such a software platform developed by the authors enables the possibility to test novel techniques tailored to the new features of the Galileo signals (BOC modulation and longer primary and secondary codes).

The software tool is composed by a novel acquisition stage for a coarse evaluation of the satellite parameters and an adapted tracking loop made by a Delay Lock Loop (DLL) and Phase Lock Loop (PLL) loops designed for the GIOVE-A signals. Thus, it allows the post processing of the collected data and to evaluate the main satellite signal parameters.

4 Data Collection

Using the system described in the previous section, several minutes of the signal have been recorded.

The signal samples have been collected on the hard disk drive during the pass of GIOVE-A above Torino (Italy) on 1st March, 2006 starting form 12 AM to 12.30 AM. During that time the satellite reached a maximum elevation angle of 39°.

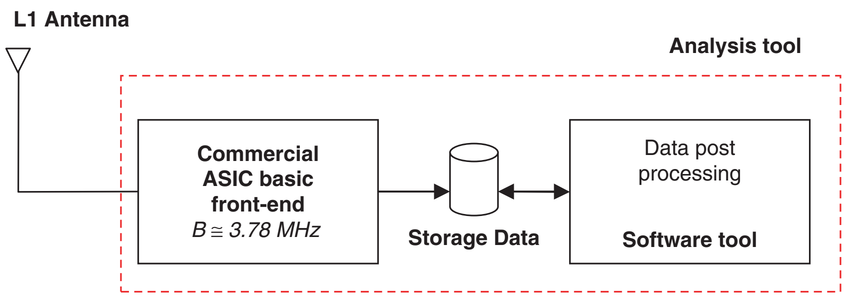

Fig. 2. Block diagram of the experimental setup.

5 Processing Results

The aim of this work is the evaluation of both the acquisition and tracking phases on the signal broadcasted by GIOVE-A. In this paragraph the most significant results obtained post processing the real GIOVE-A signal sample are shown, as far as the acquisition and tracking phase are concerned.

5.1 Acquisition

This section describes the GIOVE-A signal acquisition process deployed in the Software tool.

Acquisition is a coarse synchronization process which produce outputs on estimation of the PRN code offset and of the carrier Doppler shift. This information is then used to initialize the tracking loops.

As already mentioned, Galileo is expected to use longer codes with respect to GPS, as the one currently transmitted by GIOVE-A. Moreover, the code structure foreseen is the so called "tiered codes" where a longer primary code is modulated by a short, lower rate, secondary code.

In order to deal with the presence of bit transitions on the data channel and of the secondary code on the pilot channel, in the acquisition phase a Partial Correlation method has been employed in the search space evaluation. This approach consists in correlating the incoming signal with the local code, as for the case of the standard approach, but using a time window shorter than a code period.

As Fig. 3 shows, considering the code period of the incoming signal 4 ms long for the Data channel or 8 ms long for the Pilot channel, the local code could be created only 2 ms long instead of using the whole code length. The principle behind this method is to perform the correlation between the shorter local code and the incoming signal moving the local code from a particular position as in Fig. 4(a) to the position with the maximum correlation peak as in Fig. 4(b) finding the best matching between the two sub-portion of the PRN codes. Even if the correlations are not made on the whole code period the acquisition is still possible, even if, of course loss in the correlation performance is experienced.

In order to reduce as much as possible the losses due to the coarse Doppler shift estimation, the doppler bin size in the search space must be accurately designed. It can be proved that the doppler resolution is related to the coherent integration time:

$$D = \frac{1}{T} \quad (4)$$

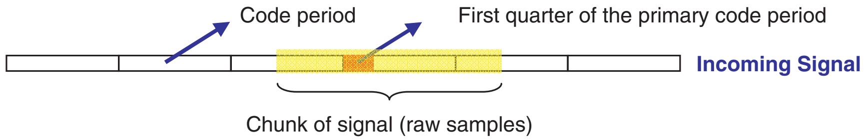

Fig. 3. Partial Correlation example.

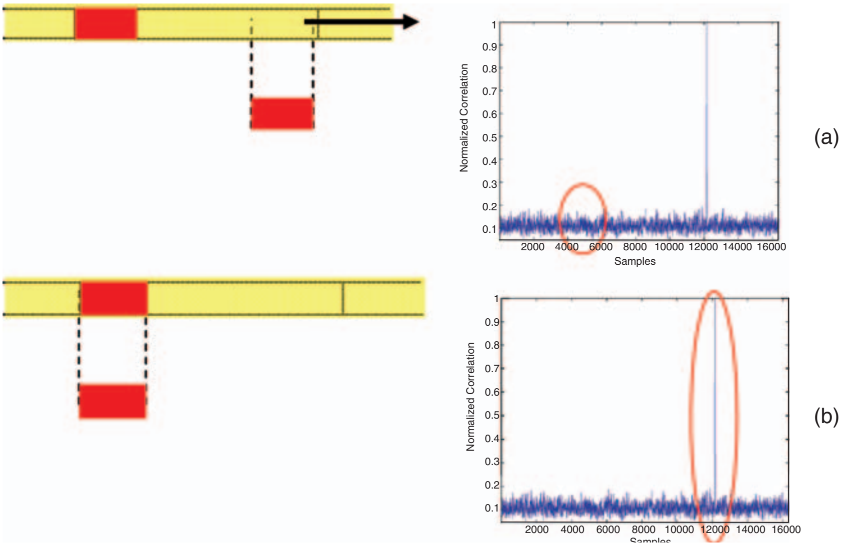

Fig. 4. Partial correlation method.

where D is a frequency bin width in Hz and T is the predetection integration time in seconds [5]. The problem arises with long code periods as in the GIOVE-A signal. In this case the bin width is small (250 Hz for Data channel e 125 Hz for Pilot channel) and this means that in order to cover the full range of uncertainty (usually from −5KHz to 5KHz for a user) the computational burden for the acquisition algorithm becomes unacceptable. For this reason, if the correlation is performed over a shorter time window, the frequency step can be increased maintaining the losses identical to the one with long integration time.

In other words, this means that this method has the advantages of reducing the computational load and the so called receiver time to first fix, but due to the fact that it does not fully exploit the code correlation characteristics the acquisition performed are reduced due to the larger correlation loss [6].

It must be noted that with the new structure of the signal this techniques can be applied to both the Data and the Pilot channels. As an example, Fig. 5 shows the signal acquisition on the Pilot Channel. As it can be observed in the Search Space plot of Fig. 5, the correlation peak pops out form the noise floor resulting in a visible and clean peak. Fig. 6 depicts the code correlation for the doppler row which provides the highest peak, it is possible to see both the main peak and the two side peaks due to the BOC modulation.

5.2 Tracking

As far as the signal tracking is concerned, the paper shows how the adopted double loops, composed by a PLL and DLL track the GIOVE-A signal.

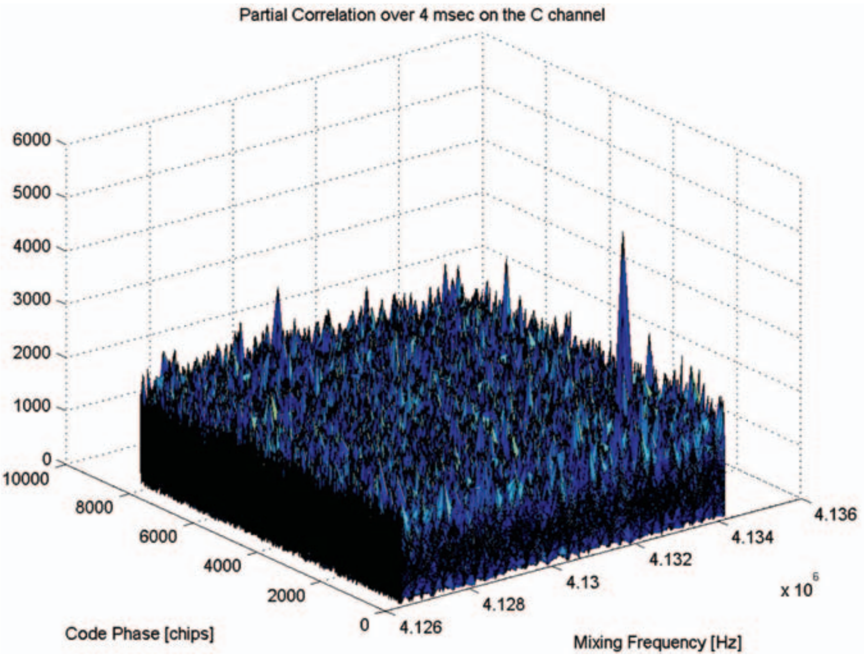

Fig. 5. Acquisition on pilot channel – search space.

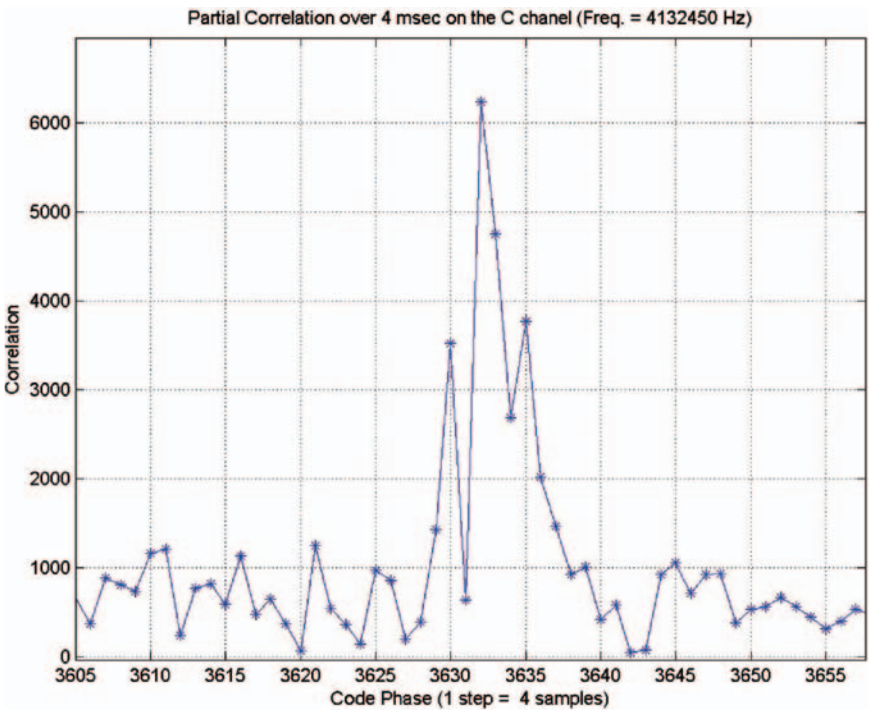

Fig. 6. Acquisition on pilot channel – autocorrelation peak.

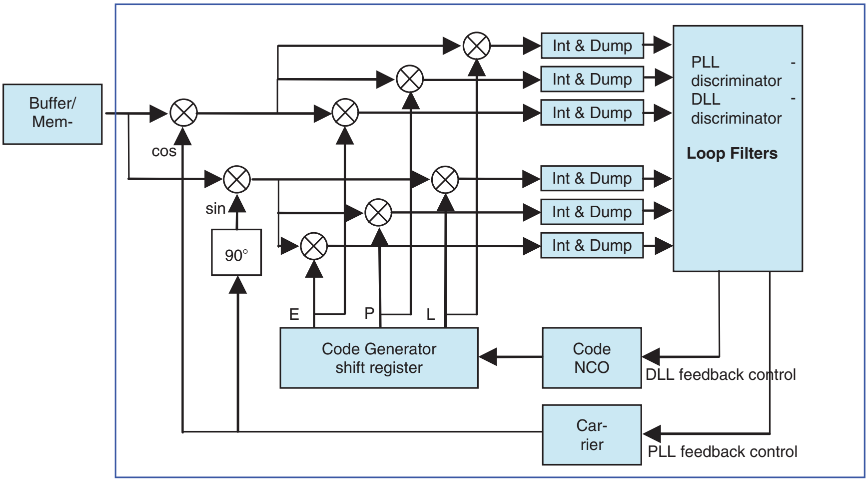

Fig. 7. Tracking block diagram.

After the acquisition process the control is then handed to the tracking loops. This part is able to track the variation in the carrier Doppler and code offset due to the line of sight dynamics between satellite and receiver. Another important function of the tracking loops is to demodulate the navigation data from the incoming signal.

Figure 7 shows the block diagram of the tracking core of the Software tool, where the received PRN code is synchronized with a locally generated code. This operation is at the basis of a GNSS receiver and the overall performance depends on the accuracy of such synchronization.

The tracking system was set up with a second order tracking and code loops with a bandwidth equal to 60 Hz and 5 Hz respectively. The PLL was a Costas PLL and the DLL was configured with a normalized dot product discriminator. Both the loops use a PI filter and the E-L spacing was set equal to 0.5 chips.

Choosing the right local code in the Software tool both the Data channel and the Pilot channel can be tracked.

As it is shown in Fig. 8, once the DLL and PLL are locked, data bits are visible at the output of Prompt in phase channel while the output of the quadrature channel is noisy.

Looking at Fig. 9, which shows the early, prompt and late correlator outputs for the Data channel, it is evident that the DLL is able to keep the local and incoming codes synchronized. In fact the early and the late outputs assume the same values over all the seconds of processed data. The DLL loop become stable after a short transient time, which depends on the loop bandwidth set.

Furthermore, such values are equal to half the prompt output, since the early-minus-late DLL was used (delay between the early and late is equal to 0.5).

Figure 10 shows the increment of the local carrier frequency with respect to the nominal value (4.1304MHz). Note that the mean of the local frequency tends to increase. Since the satellite is moving with respect to the receiver, the incoming

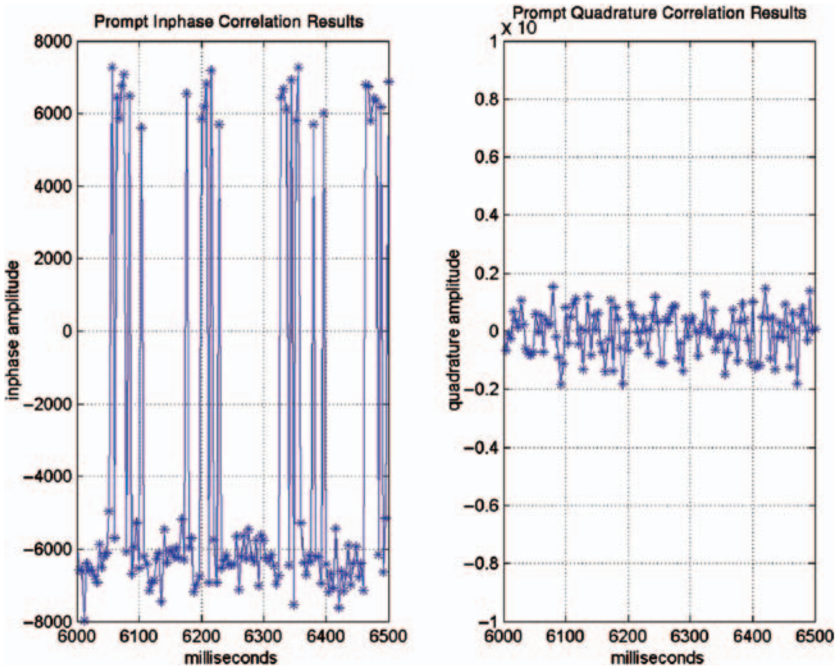

Fig. 8. Prompt quadrature and inphase channels – data channel.

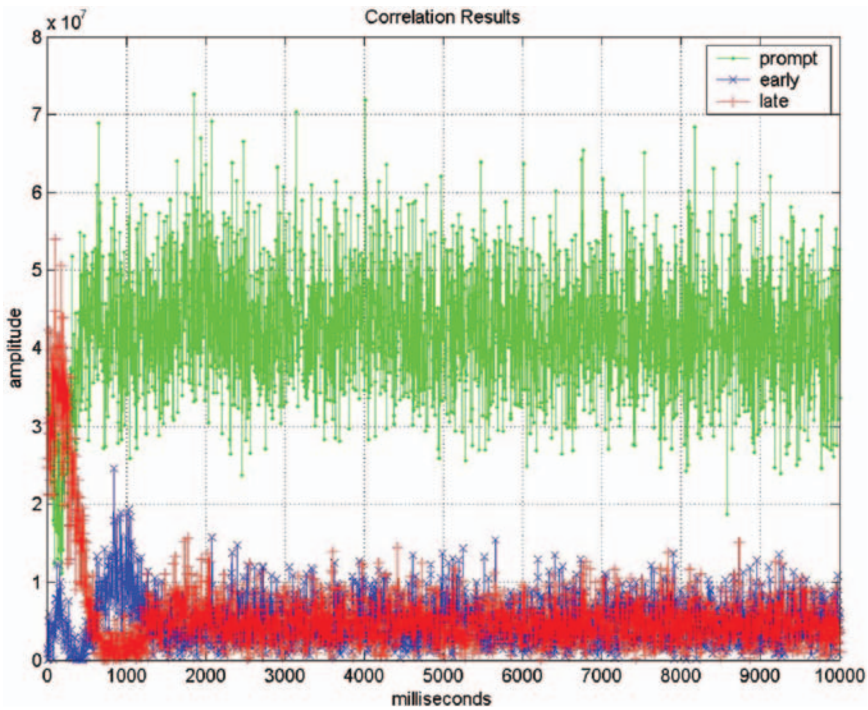

Fig. 9. Code discriminator output of the data channel.

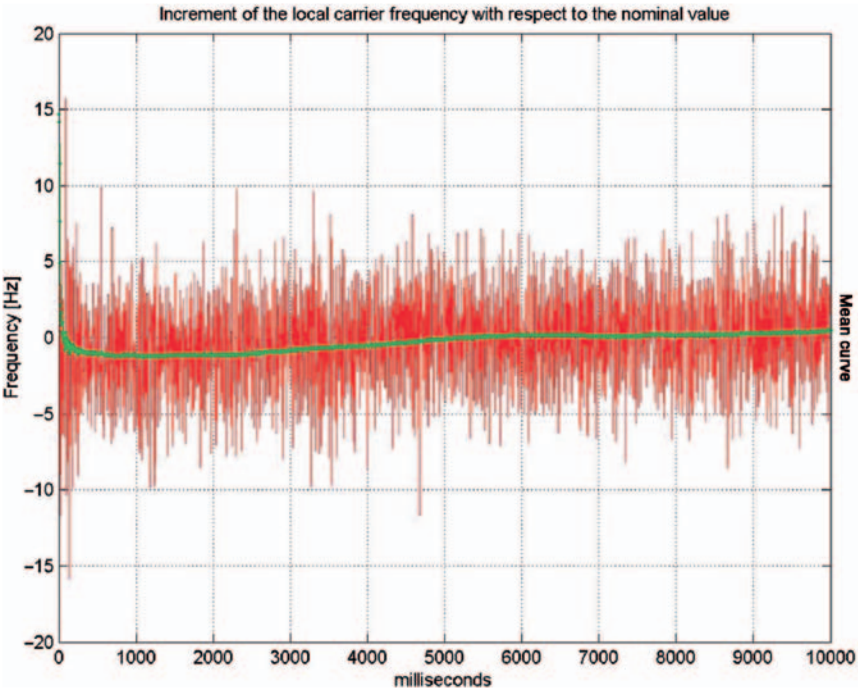

Fig. 10. Carrier tracking – data channel.

signal is frequency modulated due to the Doppler effect. The PLL is locked and the local frequency changes as well.

Thanks to the modularity of the Software tool the GIOVE-A signal has been tracked using also the Pilot channel. The Pilot channel has long code period, and integrating over a longer period, the loop control signals are sent back only once every 8 ms, but the noise impact is reduced as Figs. 12 and 13 show.

At the output of Prompt in phase channel it is visible the secondary code of GIOVE-A Pilot channel as depicted in Fig. 11, while only noise is present at the quadrature channel.

Looking at Fig. 12 it is evident that the DLL is synchronized with the incoming signal in fact the Prompt channel is higher than the early and late, which assume almost the same values.

Also the PLL, after a transient time, follows the carrier frequency and the shape of the output curve shown in Fig. 13 is consistent with the one depicted in Fig. 10.

6 Conclusion

This work has shown the basic signal processing for a GNSS receiver on the signal broadcast by the first Galileo satellite: GIOVE-A.

The new structure of the signal (longer primary codes, BOC modulation, use of a pilot channel with a secondary code, higher data rates) forces to change the common

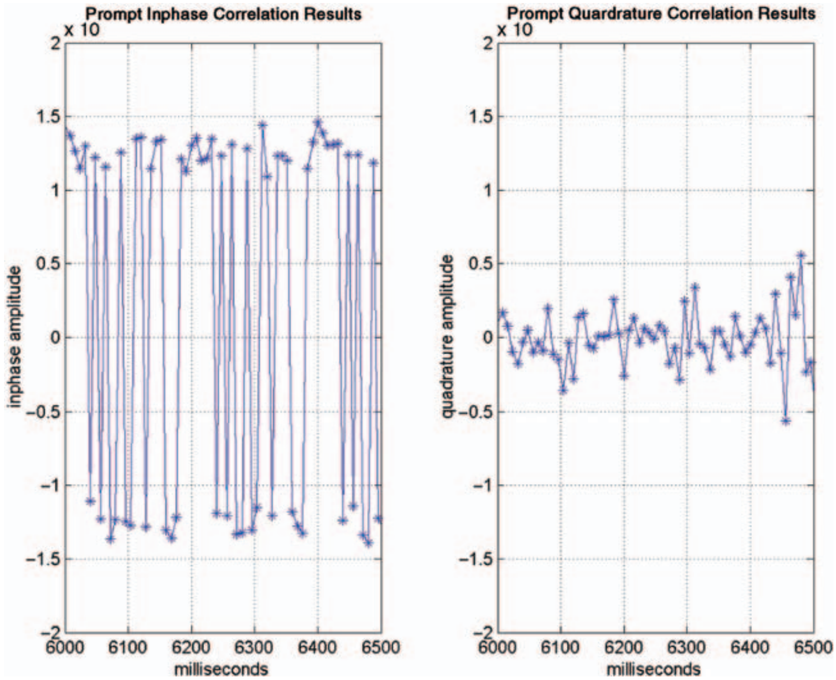

Fig. 11. Prompt quadrature and inphase channels – pilot channel.

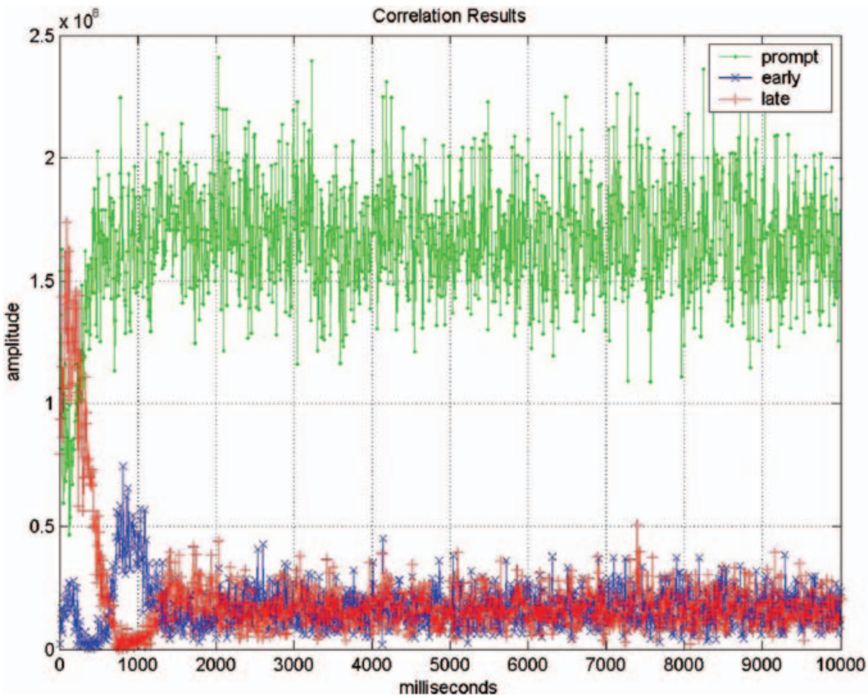

Fig. 12. Code discriminator output of the pilot channel.

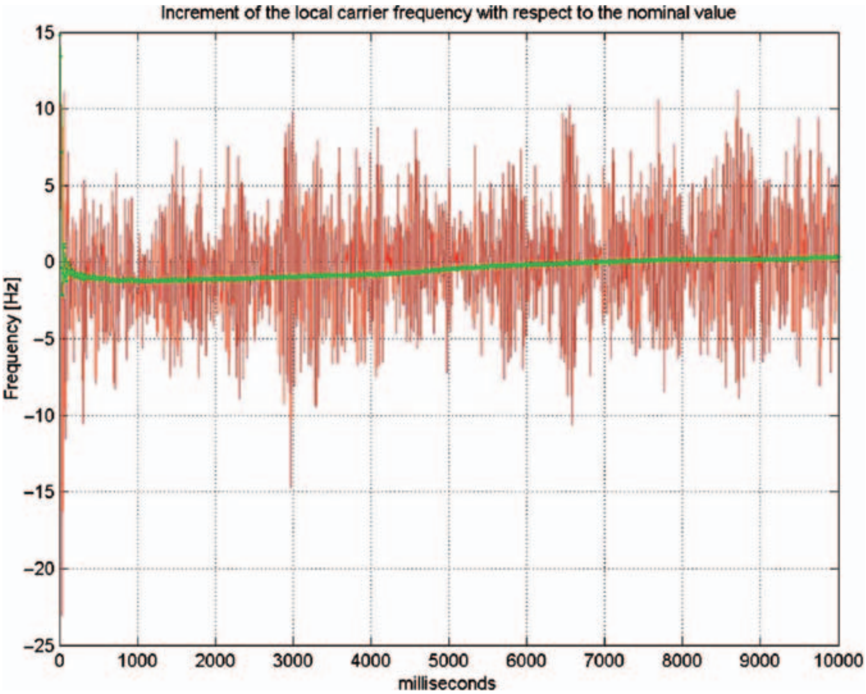

Fig. 13. Carrier tracking – pilot channel.

acquisition and tracking strategies usually adopted for GPS. For this reason the signal broadcast by GIOVE-A was acquired using the Partial Correlation and tracked on both the Data and Pilot channels.

The experiment performed on real data sets allowed to validate and better understand previous works based on simulated Galileo signals, and represent a first step for the test of novel receiver architectures tailored to the new features of the open service Galileo Signal In Space (SIS).

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