TRANSNAV International Journal on Marine Navigation and Safety of Sea Transportation
Volume 4 Number 1 March 2010

Galileo AltBOC E5 Signal Characteristics for Optimal Tracking Algorithms

F. Vejrazka, P. Kovar & P. Kacmarik
Czech Technical University in Prague, Czech Republic

ABSTRACT: The paper deals with an optimal processing of a Galileo E5 signal. A proposed correlator structure was developed on a base of a deep study of an E5 signal cross correlation function. Due to the non linearity of the E5 AltBOC modulation the proposed correlator calculates the cross correlation function between a received signal and a signal replica for all possible hypotheses of the navigation message bits. A correct peak tracking verification is realized by implementation of a single side band correlator, which also serves for course signal acquisition and secondary ranging code synchronization. The signal processing was verified on the Galileo Giove A and Giove B satellites with very positive preliminary results.

1 INTRODUCTION

The Galileo system is a civil satellite navigation system currently developed by the European Union. The system will provide different types of services for various missions, from a basic so called open service (OS) to safety of life service (SoL) and public regulated service (PRS). The Galileo signal structure is therefore very complicated and utilizes wideband signal with an AltBOC modulation for high precision range measurement.

This paper is focused on the signal processing methods of complete AltBOC Galileo E5 signal, which is the most complex Galileo signal with the widest frequency bandwidth. The optimal methods of the GNSS signal processing are well known and are based on the correlation reception. The navigation receiver calculates cross correlation function of the received signal and a locally generated replica signal and synchronized the replica on the received signal.

The optimal correlator structure for Additive White Gauss Noise Channel (AWGN) is the classical Early-Late correlator. The structure of such correlator for GPS L1 C/A signal can be found in Kaplan (1996). The replica generation for GPS L1 C/A signal is very simple, because the unknown navigation data bits are modulated by the linear BPSK modulation.

The proposed signal processing algorithm for the GALILEO E5 signal is based on the same principles like the GPS L1 C/A processing, but the correlator structure is more complex.

2 GALILEO E5 SIGNAL CHARACTERISITC

The Galileo signals are defined in ESA (2008). The cross correlation function of the signal was derived in Kačmařík (2008) and can be written as follows

$$R_{sr_{E5}}[m] = \left(\frac{1}{2\sqrt{2}}\right)^2 \frac{1}{S}\left(\Re[m] + \mathrm{j}\Im[m]\right), \tag{1}$$

where

$$\begin{aligned}\Re[m] = &\sum_{n=-\infty}^{\infty}\left[\begin{matrix}\left(R_{sr1}[n]+R_{sr2}[n]+R_{sr3}[n]+R_{sr4}[n]\right)\cdot\\ \left(\rho_{11}[m-nSN]+\rho_{22}[m-nSN]\right)\end{matrix}\right]+\\ &+\sum_{n=-\infty}^{\infty}\left[\begin{matrix}\left(\bar{R}_{sr1}[n]+\bar{R}_{sr2}[n]+\bar{R}_{sr3}[n]+\bar{R}_{sr4}[n]\right)\cdot\\ \left(\rho_{33}[m-nSN]+\rho_{44}[m-nSN]\right)\end{matrix}\right]\end{aligned} \tag{2}$$

and

$$\begin{aligned}\Im[m] = 2&\sum_{n=-\infty}^{\infty}\left\{\begin{matrix}\left(R_{sr1}[n]+R_{sr2}[n]-R_{sr3}[n]-R_{sr4}[n]\right)\cdot\\ \rho_{12}[m-nSN]\end{matrix}\right\}+\\ +2&\sum_{n=-\infty}^{\infty}\left\{\begin{matrix}\left(\bar{R}_{sr1}[n]+\bar{R}_{sr2}[n]-\bar{R}_{sr3}[n]-\bar{R}_{sr4}[n]\right)\cdot\\ \rho_{34}[m-nSN]\end{matrix}\right\}\end{aligned} . \tag{3}$$

The replica signal of the Galileo E5 signal depends on four secondary code bits and two navigation message bits. Since the secondary codes of the data channels are multiplied by the navigation message bits, the cross correlation function generally depends on four bits. It results in sixteen possible shapes of the cross correlation function between received signal and generated replica. All of them are depicted in Figure 1, where 1 or -1 in a chart title indicates bits agreement or disagreement respectively.

The secondary code bits are known in the receiver and can be generated after secondary codes synchronization, but the navigation message bits remain unknown.

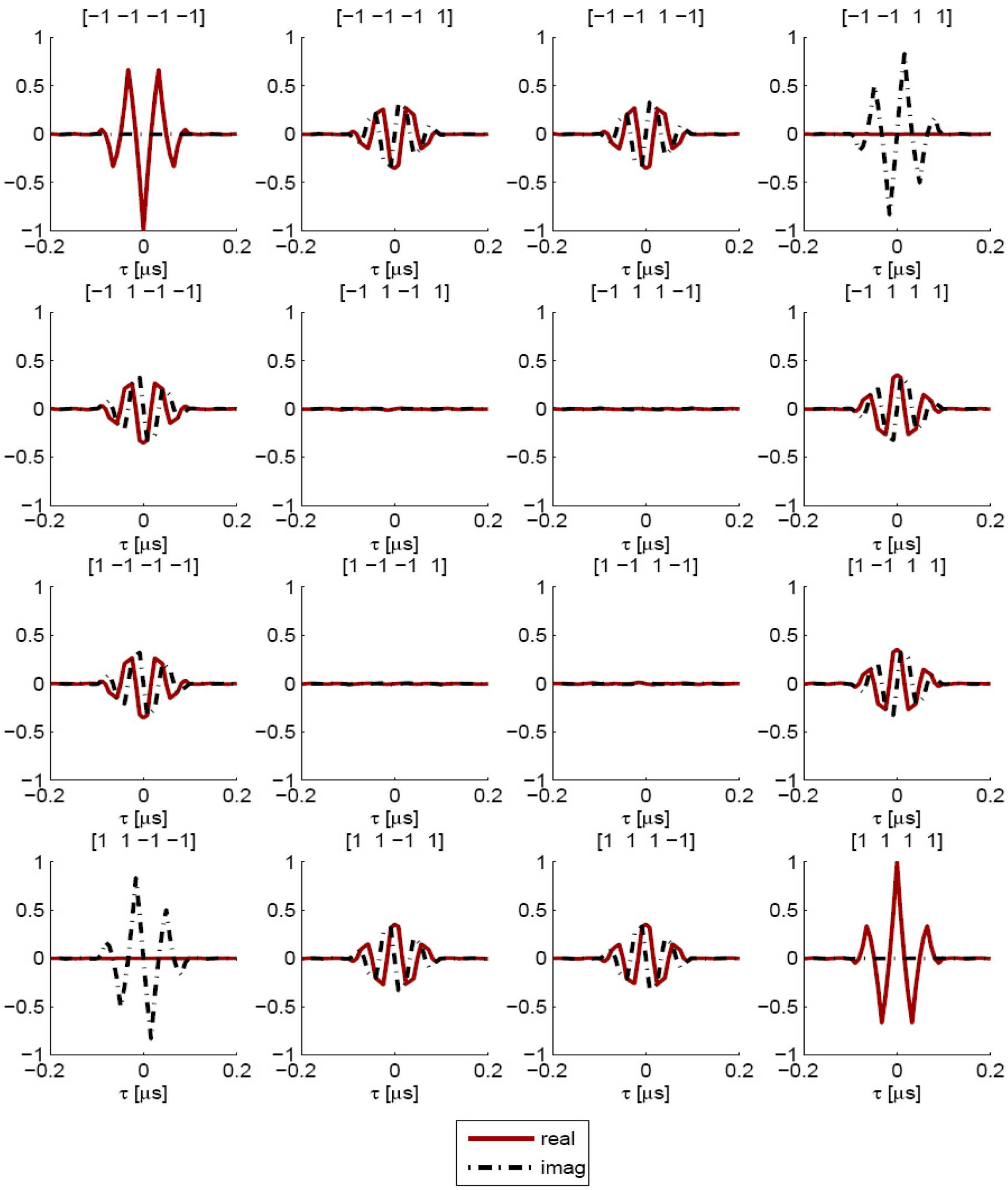

Figure 1. Cross correlation function of received signal and replica for all combination of secondary codes bits

3 E5 CORRELATOR

The structure of the Early - Late correlator for Galileo E5 signal is complicated since the complex AltBOC modulation is used. There is no linear dependency of the modulated signal on the navigation message bits like in the GPS L1 C/A signal. The replica signal therefore must be generated for all possible hypotheses of the navigation unknown parameters. In general case we have to generate 16 replicas. The number of hypotheses can be reduced on four hypotheses after the secondary code synchronization.

This approach gives rise to the correlator structure shown in Figure 2. The first four correlator branches serve for a calculation of the cross correlation function for all combinations of the navigation message bits. The fifth branch supports final signal acquisition, secondary code synchronization and also verification of the correct correlation peak tracking. This correlate branch processes only one signal component of the Galileo E5 signal.

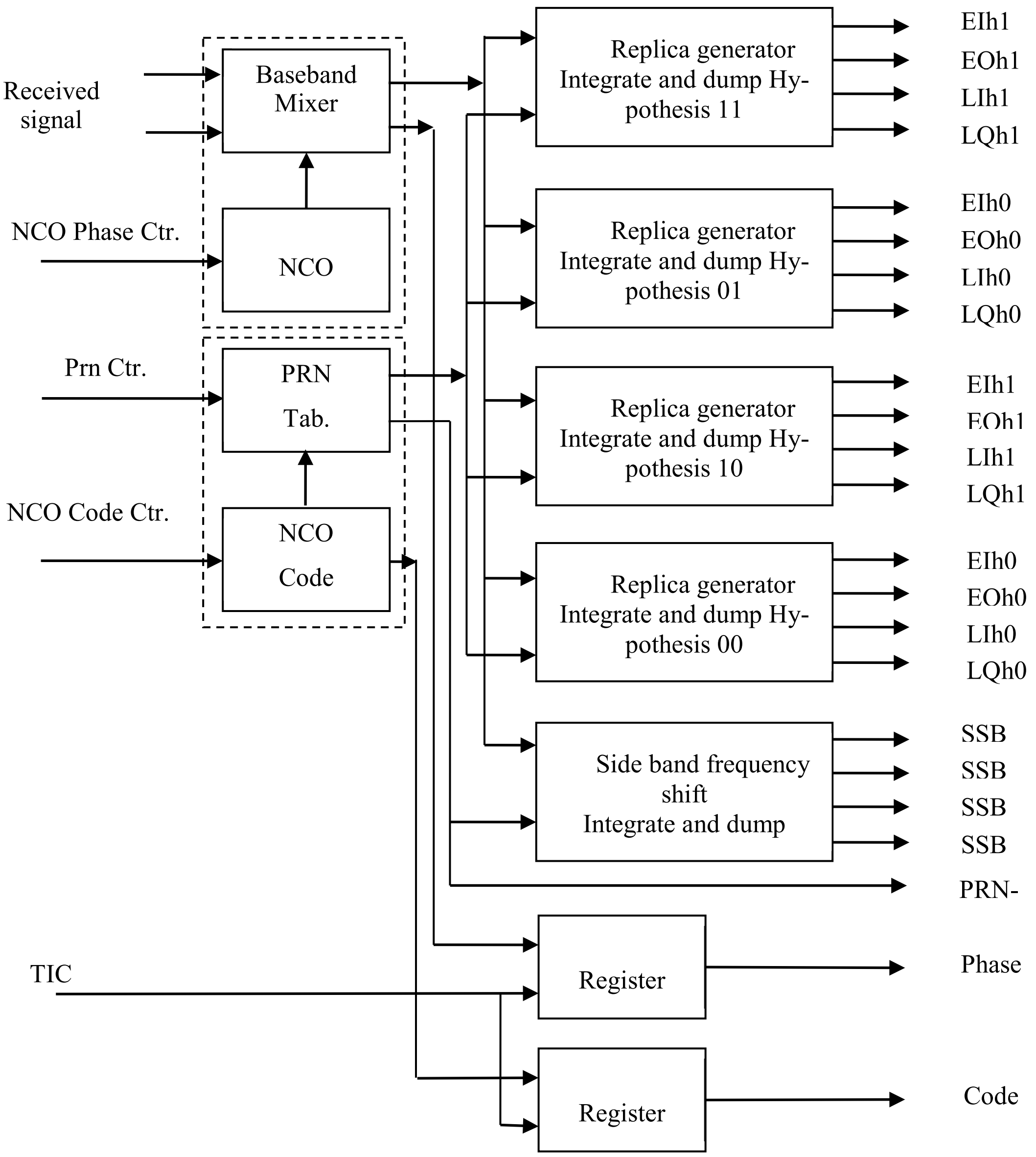

Figure 2. Galileo E5 correlator structure

4 CORRELATOR VERIFICATION

The proposed Galileo E5 correlator was verified by the live Giove A and Giove B signals and on the Galileo E5 signal generated by a signal generator. This signal is processed by the GNSS software receiver EGR 2 which has been developed at the Czech Technical University since 2000.

The block diagram of the receiver is drawn on Figure 3. The Galileo signal is received by the wideband GNSS antenna equipped with the low noise high dynamic range amplifier. The next receiver block is a selective amplifier which splits partial GNSS signals on L1 (E1), L2 and E5 (L5) frequencies. The E5 signal is processed by a zero intermediate frequency receiver. The base band signal is digitalized and processed in Virtex 5 FPGA. The measured data is sent via Ethernet to the PC workstation for further processing.

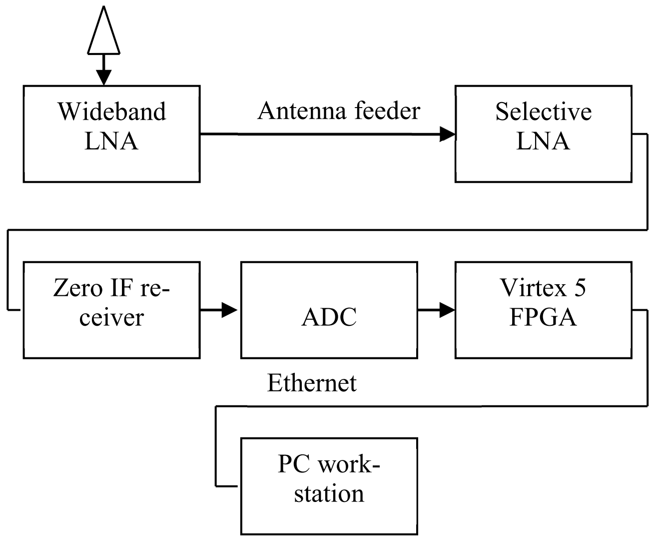

Figure 3. EGR 2

The proposed Galileo E5 correlator was developed in Matlab Simulink using with Xilinx System Generator Toolbox. The correlator is controlled by the embedded processor also integrated into the FPGA.

5 EXPERIMENTAL RESULTS

This paragraph presents preliminary results of the implemented Galileo E5 correlator. The results were obtained by the receiver with not fully optimized DLL and a PLL tracking loops. The signal was received by the experimental antenna system equipped with a helical RF filter. The noise figure of this antenna is proximately 5 dB.

The plot of the pseudo range error and the carrier phase error for the Galileo Giove A and Giove B satellites are plotted on Figures 4 and 5. The standard deviation of these errors is in Table 1.

We are going to repeat these experiments with higher performance GNSS antenna based on PHEMT LNA with a noise figure 1 dB and a higher performance selective LNA populated with the low insertion loss and low distortion coaxial resonators filters and with the fully optimized DLL and PLL tracking loops. We believe that we will reach better performance.

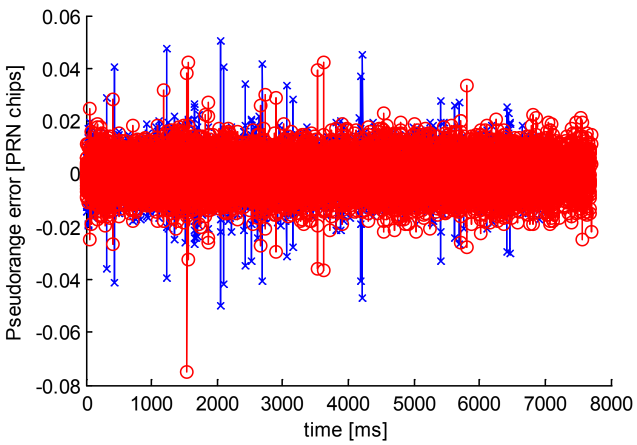

Figure 4. Code tracking error (× - Giove A, ○ – Giove B)

Table 1. Code and phase tracking error

Satellite	Giove A	Giove B
Standard deviation of code tracking error [m]	0.202	0.204
Standard deviation of phase tracking error [mm]	2.83	2.81

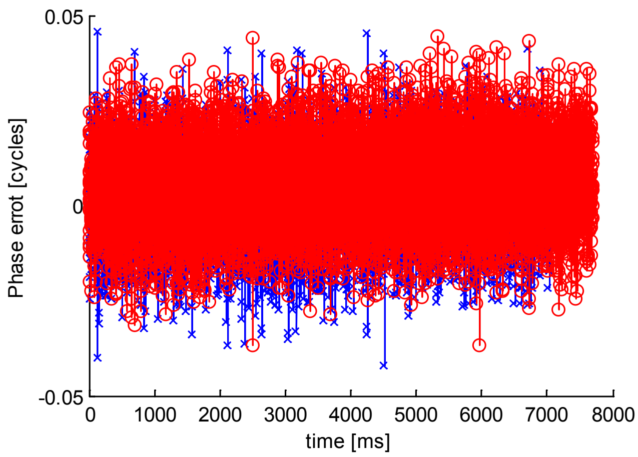

Figure 3. Phase tracking error (× - Giove A, ○ – Giove B)

6 CONCLUSIONS

This paper presents the Galileo AltBOC E5 signal characteristics and on their base proposes the structure of the optimal Galileo E5 correlator for the AWGN channel. The structure of the proposed correlator is complicated due to the non linearity of the AltBOC modulation of the navigation message bits which requires to calculate the cross correlation function between the received signal and the replica for four hypotheses.

The developed correlator was tested in the software receiver on the live Galileo signals with the promising preliminary results. The final test is planed to realize with the higher performance reception antenna and with the fully optimized PLL and DLL tracking loops.

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