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Scientific and Technological Experiments on Automatic Space Vehicles and Small Satellites

Acquisition of E5 Galileo signals in Matlab

Ekaterina Stepanova[a] *, Ilya Kudryavtsev[a], Elena Simona Lohan[b]

[a]*Samara State Aerospace University, Moskovskoye shosse 34, Samara 443086, Russia*
[b]*Tampere University of Technology, Korkeakoulunkatu 10, FI-33720 Tampere, Finland*

Abstract

The deployment of Galileo constellation leads to the need of efficient algorithms for acquisition and tracking of Galileo signals. These signals are different from GPS signals and this difference should be taken into consideration in the program code. This paper deals with the acquisition of Galileo signals in Matlab. The code is developed on the basis of the free code developed by Kai Borre for GPS Software defined radio [1].

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Keywords: acquisition; AltBOC modulation; autocorrelation function (ACF); Galileo signal; Matlab; navigational signal; program code.

1. Introduction

Galileo satellites transmit several signals on different frequencies aimed to four main purposes – open service, safety-of-life service, commercial service, public regulated service. In the paper we will consider signals meant for open service – the E5 signal with the central frequency 1191.795MHz, which has two components: E5a (1176.45 MHz) and E5b (1207.14 MHz). These Galileo signals use Alternate BOC (AltBOC) modulation [2].

Alternate BOC modulation is based on standard BOC (Binary Offset Carrier) modulation where the signal is multiplied by binary subcarrier and harmonic carrier. The aim of using AltBOC modulation is to generate coherent components E5a and E5b. Resulting signal may be received as a wide-band BOC signal. Both signals (E5a and E5b)

* Corresponding author.
E-mail address: ek.step@mail.ru

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contain information in in-phase (I) and quadrature (Q) parts. The E5a code is shifted into the lower frequency band and E5b is shifted into the upper frequency band. Quadrature components of E5a and E5b signals are modulated by pilot signals without data, in-phase components of E5a and E5b signals are modulated by both PRN code and data.

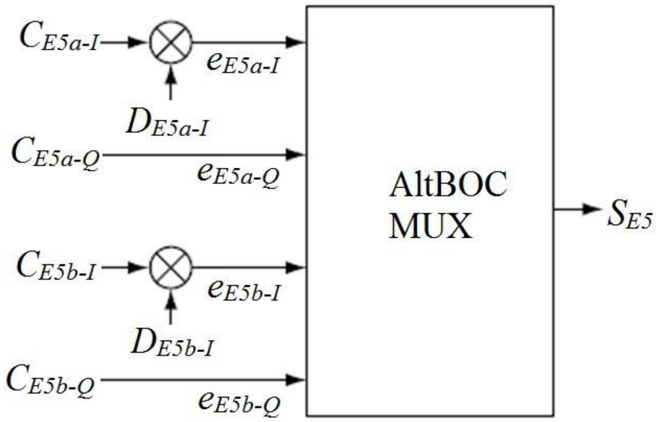

Fig. 1. Modulation scheme for Galileo E5 signal (reproduced from [2])

Thus, Q-channels are free from additional phase shifts. This can make acquisition process easier [3]. The process of signal generation is represented in the Fig. 1. In this figure:

- CE5a-I and CE5b-I – PRN code sequences for E5a and E5b data channels respectively;
- CE5a-Q and CE5b-Q - PRN code sequences for E5a and E5b pilot channels respectively;
- DE5a-I and DE5b-I – E5a and E5b navigation data stream respectively;
- eE5a-I and eE5b-I – E5aI and E5bI signal components (i.e. E5a and E5b data signals) respectively;
- eE5a-Q and eE5b-Q – E5aQ and E5bQ signal components (i.e. E5a and E5b pilot signals) respectively;
- SE5 – resulting E5 signal.

E5a and E5b signals may be processed separately as usual BPSK signals or together, providing higher accuracy and better noise filtration in multipath conditions, what can be considered as an advantage of using AltBOC modulation.

2. Matlab code

The frequency-domain based acquisition process, used in GPS receivers is well-known and described in details in [1], where it was implemented in Matlab, using a relatively simple Fast Fourier Transform (FFT) approach, where the output IF signal of the RF Front-End signal was acquired. The reception of Galileo signals may be done in several ways. One of the most interesting approaches is a synchronous demodulation where the heterodyne has the same frequency as the incoming signal. Certainly, we encounter some problems with providing the equality of these frequencies, but they are beyond of the scope of this paper.

In this case the acquisition of signals has its peculiarities – the data processing is performed with complex Galileo signals (the characteristics of I and Q-channels were described in previous section), so we had to improve the GPS approach in order to make it applicable for the acquisition of the Galileo E5 signals.

During this modification of the original code [1] in the acquisition part, it was taken into consideration that the Galileo code is four times longer than the GPS code (4092 code length instead of 1023 chips). Besides, there are different coding principles for GPS and Galileo signals, and this fact also required substantial changes in the code. To work with complex Galileo signals the part for complex data processing was included. In this case bits of information from data file were read in the next but one sequence and then transformed in a complex form (see Fig. 2).

To generate local code for further data acquisition the Galileo signal was resampled (Fig. 3). The purpose of it is the following: the generated signal has a frequency different form sampling frequency of the incoming signal. Thai is why we need to change the frequency of the generated signal in order to process it correctly.

For acquisition of Galileo signals was introduced a complex variable (IQ, see Fig. 4) that allows to operate with I and Q-channels. In addition, as in usual approach, we used Fast Fourier transform and conjugate functions for signal acquisition.

The autocorrelation function (ACF) of Galileo signals is different from ACF of GPS signals – it has side lobes that cause problems in acquisition. These side lobes are shown in Fig. 5, this figure is obtained from the code described in [4]. We should look for the central lobe and should be sure that the signal is acquired correctly. To do this, after finding the correlation peaks it is necessary to compare them and find the higher peak – it will be the required central lobe.

```
% Read data for acquisition. 11ms of signal are needed for the fine
% frequency estimation
if settings.IF~=0
data=fread(fid, 11*2*samplesPerCode, settings.dataType)';
else
data=fread(fid, 11*4*samplesPerCode, settings.dataType)';
data1=data(1:4:end);
data2=data(4:4:end);
data=data1+1i.*data2;
end
```

Fig. 2. Transformation of the data into the complex form

```
%--- Generate Galileo code for given PRN and add BOC modulation------------------------------------------
caCode = generateGalileoCode(PRN);

codeBipolar = zeros( 1, 2 * length( caCode ) );
codeBipolar(1:2:end) = 1-2*caCode;              % Positive part of the BOC(1, 1) subcarrier
codeBipolar(2:2:end) =-codeBipolar(1:2:end);    % Negative part of the BOC(1, 1) subcarrier

% Resample code at sempling frequency

tVec = ( 0:1:(samplesPerCode-1) )/settings.samplingFreq;
resampledCode = codeBipolar(mod(floor(tVec*2*settings.codeFreqBasis),length(codeBipolar))+1);
```

Fig. 3. Resampling of Galileo signal

```
fin=settings.IF/settings.samplingFreq;
dopStepNorm=dopStep/settings.samplingFreq;

acquiredSpace=zeros(Nd, settings.samplingFreq/settings.codeFreqBasis);

freq=conj(fft(resampledCode));
t=0:(N-1);

for i=1:Nd,
    fc=fin+(i-ceil(Nd/2))*dopStepNorm;
    IQ=exp(-2*1i*pi*fc.*t).*data;
    Y=fft(IQ);
    acquiredSpace(i,:)=ifft(Y.*freq);
end

acquiredSpace=real(acquiredSpace.*conj(acquiredSpace));
```

Fig. 4. Process of acquisition

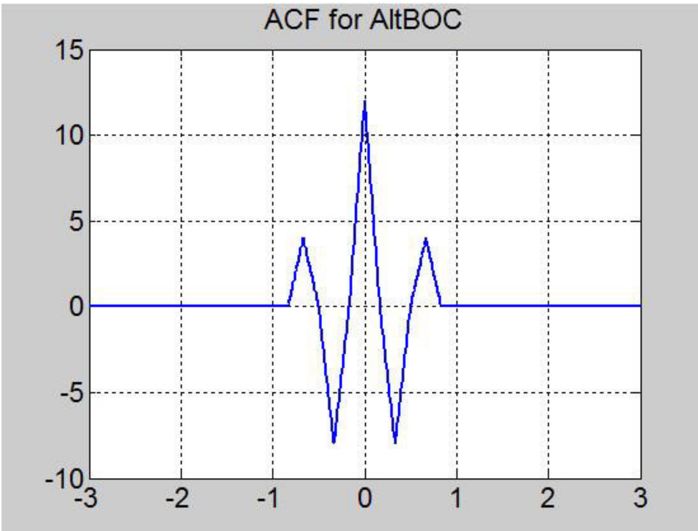

Fig. 5. Real part of the ACF for ideal AltBOC-modulated Galileo signal

3. Results

To compare Galileo and GPS codes, we used the data files kindly provided by prof. Gonzalo Seco-Granados (UAB, Spain), which he and his research team received in February, 2014. Then we perform an acquisition, using the code, described above. The experiment was carried out with two levels of signal to noise ratio (SNR): -20dB and -30 dB. The obtained auto correlation functions (for Galileo and GPS signals) are shown in Fig. 6 and Fig. 7, respectively.

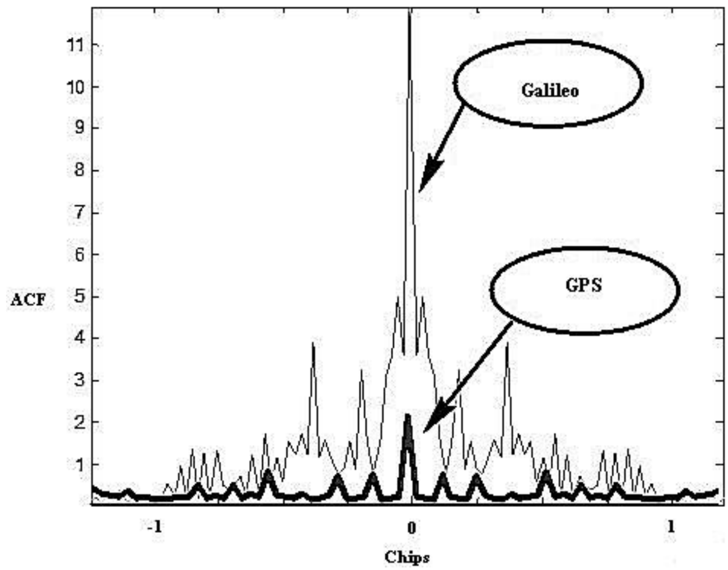

Fig. 6. ACF of GPS and Galileo signals comparison. SNR=-20dB

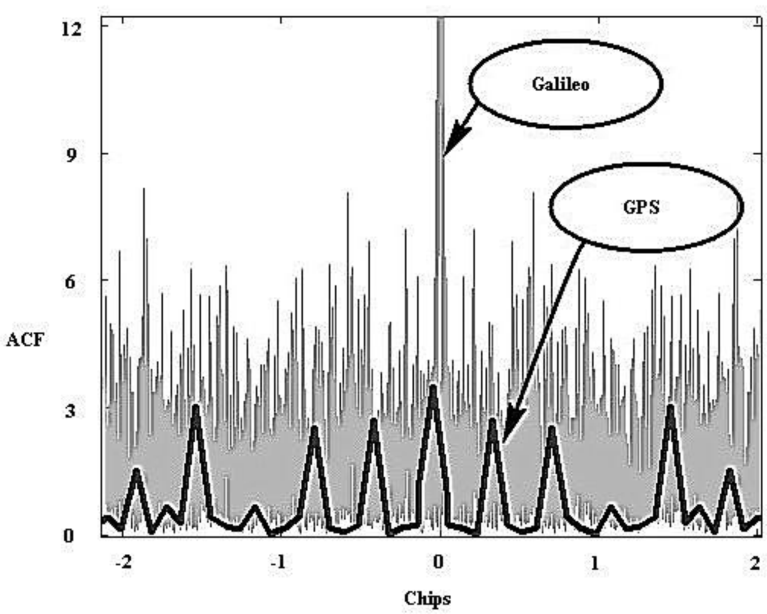

Fig. 7. ACF of GPS and Galileo signals comparison. SNR=-30 dB

It can be seen that in case of SNR=-20dB acquisition of Galileo signals is much more reliable and provides better accuracy. This means that there is a possibility of acquiring the Galileo signals with higher levels of noiseб like shown in Fig.7. It is evident, that acquisition of GPS signal couldn't be successful, when SNR=-30dB, unlikely the one of Galileo signal.

Besides higher peak, the ACF of Galileo has a narrower main lobe, because of a higher chip rate. The chip rate in GPS is 1.023 MHz and the chip rate in the AltBOC Galileo signal is 10.23 Mhz. This explains the lower width of the main lobe in the ACF of Galileo compared with GPS. This feature allows to perform more accurate acquisition of the signal. Fig. 8 and Fig. 9 displays ACF within the range of one chip code delay for Galileo and GPS signals

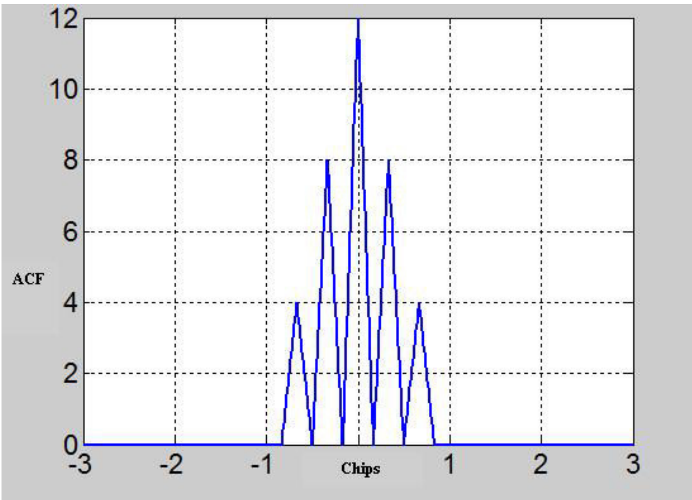

Fig. 8. ACF of Galileo signal

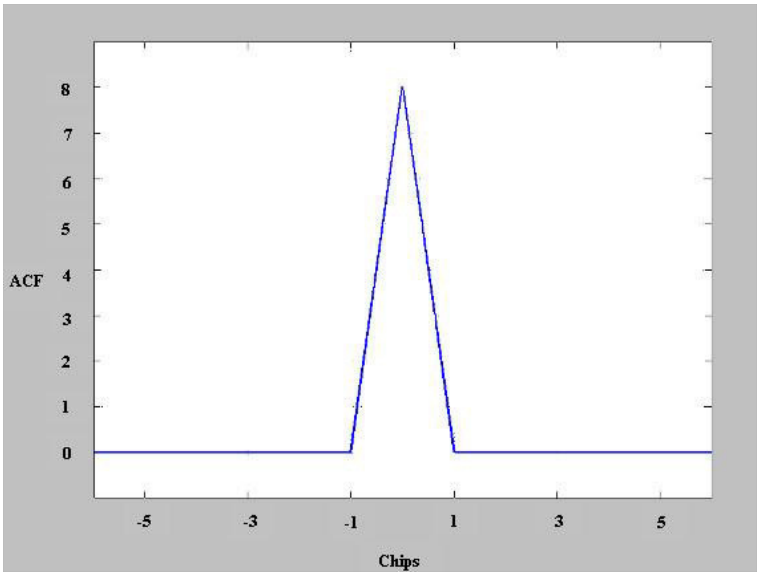

Fig. 9. ACF of GPS signal

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