ELectronics EXpress

A novel acquisition scheme for Galileo E1 OS signals

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Abstract: CBOC is the final choice of Galileo E1 OS signal. It is a result of multiplexing BOC(6,1) with BOC(1,1). It has a main drawback that is the autocorrelation function has multiple side-peaks, which will lead to ambiguous acquisition. In this paper we propose a novel method to accomplish unambiguous acquisition. The acquisition scheme is first described, and the mathematical model is introduced. Finally, the performance of this method is analyzed. This method shows very good and interesting results, cancelling the side peaks of the autocorrelation function completely and decreasing the total acquisition time especially in the case the Doppler frequency step is very small.

Keywords: CBOC, Galileo E1 OS signal, unambiguous acquisition
Classification: Electron devices, circuits, and systems

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1 Introduction

The family of Global Navigation Satellite Systems (GNSS) has been developing fast in recent years, composed of the Chinese Compass, the American GPS, the European Galileo and so on. New signals and new modulations are adopted in

DOI: 10.1587/elex.11.20140979
Received October 14, 2014
Accepted November 4, 2014
Publicized November 19, 2014
Copyedited December 10, 2014

different systems. Composite Binary Offset Carrier (CBOC) is the final choice of Galileo E1 OS signals.

CBOC is a result of multiplexing BOC(6,1) with BOC(1,1) and the proportion of the former to the latter is 10%. The data channel is modulated with the sum of them, and the pilot is the minus. With the property of splitting spectrum, CBOC can reduce the intra-system interference and improve code delay tracking.

Nevertheless, BOC-modulated signal will lead to a main drawback that is the autocorrelation function has multiple side-peaks, which will probably result in possible false acquisition. Several techniques have been proposed in the literature.

The Sub Carrier Phase Cancellation (SCPC) method generates an in phase and quadrature sub carrier signals, getting rid of the sub carrier. Therefore, this method doubles the number of correlators because it is necessary for two channels wiping off the carrier to generate two kinds of sub carrier signal. The BPSK-like method receives upper sideband or lower sideband with local carrier frequency plus a subcarrier frequency or minus one [1]. If only single sideband is received, it will bring some power loss. But the process of both sidebands will consume more correlators. ASPeCT method combines two kinds of autocorrelation functions to formulate a new one. After that, the new autocorrelation function still has small side peaks [2].

In this paper, a new method to accomplish unambiguous acquisition of Galileo E1 signal is proposed. At first, the property of CBOC is described. Then, the scheme of new method is proposed. The performance is analyzed and the results are given. A conclusion will be drawn in the end.

2 A novel acquisition scheme for Galileo E1 OS signal

Galileo E1 OS CBOC signal can be expressed as:

$$S(t) = \frac{1}{\sqrt{2}}(D(t) \times C_{E1-B}(t) \times Sub_{E1-B}(t) - C_{sec}(t) \times C_{E1-C}(t) \times Sub_{E1-C}(t)) \times cos(2\pi f_{E1} t). \tag{1}$$

Where $D(t)$ is the data, C_{E1-B} is the primary code of data channel, $Sub_{E1-B}(t)$ is the subcarrier of data channel, $C_{sec}(t)$ is the secondary code of pilot channel, $C_{E1-C}(t)$ is the primary of pilot channel, $Sub_{E1-C}(t)$ is the subcarrier of pilot channel. $Sub_{E1-B}(t)$ and $Sub_{E1-C}(t)$ can be expressed as:

$$\begin{aligned} Sub_{E1-B}(t) &= \sqrt{\frac{10}{11}}\mathrm{SinBOC}(1,1) + \sqrt{\frac{1}{11}}\mathrm{SinBOC}(6,1) \\ Sub_{E1-C}(t) &= \sqrt{\frac{10}{11}}\mathrm{SinBOC}(1,1) - \sqrt{\frac{1}{11}}\mathrm{SinBOC}(6,1) \end{aligned} \tag{2}$$

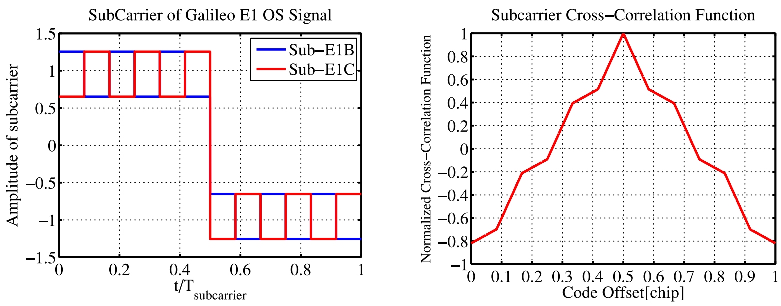
where

$$\mathrm{SinBOC(m, 1)} = \mathrm{sgn}(\sin(2\pi m f_0 t)), \quad f_0 = 1.023\,\mathrm{MHz} \tag{3}$$

$Sub_{E1-B}(t)$, $Sub_{E1-C}(t)$ [3] and the cross-correlation function (CCF) of them are shown in Fig. 1. It is shown that $Sub_{E1-B}(t)$ is in-phase and $Sub_{E1-C}(t)$ is anti-

DOI: 10.1587/elex.11.20140979
Received October 14, 2014
Accepted November 4, 2014
Publicized November 19, 2014
Copyedited December 10, 2014

IEICE Electronics Express, Vol.11, No.23, 1–7



(a) One period of SubCarriers. (b) CCF of Subcarrier

Fig. 1. SubCarriers and their CCF of Galileo E1 OS

phase. Obviously, when the delay between data channel and pilot channel is 0.5 chip, the cross-correlation will have a main peak.

CBOC is one of MBOC implementations, which places small amount of code power at higher frequencies, and improves the code tracking performance. And the Power Spectral Density (PSD) of CBOC is a combination of SinBOC(1,1) spectrum and SinBOC(6,1) spectrum, that is [4]

$$G_{MBOC}(f) = \frac{10}{11} G_{sinBOC}(1,1)(f) + \frac{1}{11} G_{sinBOC}(6,1)(f). \tag{4}$$

Where G_{sinBOC} is the normalized PSD of sinBOC(m,n)-modulated PRN code, given by [3]:

$$G_{sinBOC}(f) = \frac{1}{T_c}\left(\frac{sin\left(\pi f \frac{T_c}{N_B}\right) sin(\pi f T_c)}{\pi f cos\left(\pi f \frac{T_c}{N_B}\right)}\right)^2. \tag{5}$$

In the above equation, $m = f_{sc}/f_{ref}$ and $n = f_c/f_{ref}$, where f_{sc} is the sub-carrier frequency, f_c is the chip frequency and $f_{ref} = 1.023\,\mathrm{MHz}$ is the reference C/A code frequency. $N_B = 2f_{sc}/f_c = 2m/n$ is the BOC modulation index. CBOC autocorrelation function can be written in terms of the BOC(1,1) and BOC(6,1) autocorrelation and cross-correlation function such as

$$\begin{aligned} R_{CBOC(6,1,\frac{1}{11})}(\tau) &= \frac{10}{11} R_{BOC(1,1)}(\tau) + \frac{1}{11} R_{BOC(6,1)}(\tau) \\ &+ 2\sqrt{\frac{10}{11}}\sqrt{\frac{1}{11}} R_{BOC(1,1)BOC(6,1)(\tau)}. \end{aligned} \tag{6}$$

Where the term $R_{BOC(1,1)BOC(6,1)}$ is the cross-correlation between BOC(1,1) and BOC(6,1). PSD and ACF are shown in Fig. 2(a) and Fig. 2(b). It is shown that because of the subcarrier the normalized PSD is split and two main band locate at the frequency 1.023 MHz away from carrier frequency. And also the autocorrelation function has not only peak any more.

Obviously, there are ambiguous peaks shown in the Fig. 2(b). Also, the code phase search step will be 0.25 chip for the narrower main peaks. This paper will propose a new method to cancel the ambiguous peaks and allow the code phase search step as 0.5 chip. The framework is shown in Fig. 3.

DOI: 10.1587/elex.11.20140979
Received October 14, 2014
Accepted November 4, 2014
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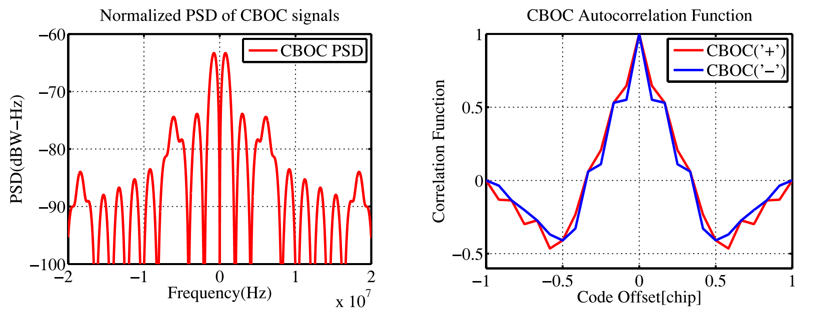
Copyedited December 10, 2014

IEICE Electronics Express, Vol.11, No.23, 1–7



(a) Normalized PSD of CBOC signals (b) CBOC Autocorrelation Function

Fig. 2. PSD and ACF of CBOC

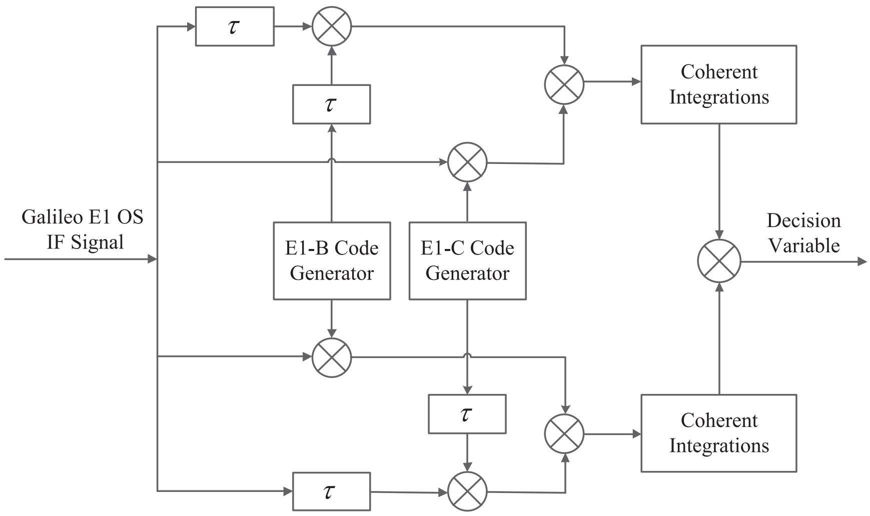


Fig. 3. Novel acquisition scheme of Galileo E1 OS signal.

At first, Galileo E1 OS Signal is delayed by τ, which can be expressed as:

$$S(t-\tau) = \frac{1}{\sqrt{2}}(D(t-\tau)\times C_{E1-B}(t-\tau)\times Sub_{E1-B}(t-\tau) - C_{sec}(t-\tau)\times C_{E1-C}(t-\tau)\times Sub_{E1-C}(t-\tau)) \times cos(2\pi f_{E1}(t-\tau)). \tag{7}$$

The delayed signal will be multiplied by the delayed C_{E1-B} and the delayed C_{E1-C}. The results are defined as $B\times C_{Delay}$ and $B_{Delay}\times C$. Finally, the decision variable is obtained by the multiplication of coherent integrations.

The $B\times C_{Delay}$ and $B_{Delay}\times C$ can be expressed as:

$$S_{X\times Y_{Delay}}(t) = \frac{1}{2}(D_X(t)\times C_{E1-X}(t)\times Sub_{E1-X}(t)) \times (D_Y(t-\tau)\times C_{E1-Y}(t-\tau)\times Sub_{E1-Y}(t-\tau)) \times \frac{1}{2}[cos(2\pi f_{E1}\tau)] \tag{8}$$

Where X,Y represent the data or pilot channel of Galileo E1 OS signal. D_X and D_Y represent the data or secondary code separately. From the discussion above, it is known that once the delay between subcarriers of data channel and pilot channel is

DOI: 10.1587/elex.11.20140979
Received October 14, 2014
Accepted November 4, 2014
Publicized November 19, 2014
Copyedited December 10, 2014

certain, the cross correlation of them has only one value. Therefore, when the multiplication of the signal and a delay of it is done, the cross correlation of subcarrier will have one certain value. In fact, the property of cross correlation of subcarrier is made use to wipe off the subcarrier. We have to make sure that the cross correlation of subcarriers will have a maximum value and $\cos(2\pi f_{E1}\tau) \approx 1$. In this way, the effect of doppler frequency is removed when the code phase is searched. At the same time, we have to make sure the CCF of subcarriers has a maximum value, which means that the delay of the signal must be 0.5 chips or (n + 0.5) chips. To make sure that the multiplication of two kinds of codes will be pseudo random sequence, τ will be larger than one code chip. Consider τ is chosen to satisfy

$$\tau \approx \begin{cases} (n+0.5)chips, & \text{where} \quad n = 1,2,3\ldots & \text{(9a)} \\ \dfrac{2k\pi}{2\pi f_{E1}}, & \text{where} \quad k = 0,1,2,3\ldots & \text{(9b)} \end{cases}$$

If the replica of code is roughly aligned with the signal's, a peak will appear after the coherent integration. And the normalized autocorrelation is shown in Eq. (10) and Eq. (11). $R_{X\times Y_{Delay}}(\Delta\tau)$ and $R_{Y\times X_{Delay}}(\Delta\tau)$ will be combined as the decision variable. We choose τ so small enough that $D(t-\tau)$ will have the same sign with $D(t)$. Therefore, it is convenient to increase the coherent integration time without effected by the bit transition.

$$R_{X\times Y_{Delay}}(\Delta\tau) = D_X(t) \times D_Y(t-\tau) \times R_{CCF-Sub}(t) \times R_{(E1-X)(E1-Y_{Delay})}(\Delta\tau) \tag{10}$$

$$R_{Y\times X_{Delay}}(\Delta\tau) = D_Y(t) \times D_X(t-\tau) \times R_{CCF-Sub}(t) \times R_{(E1-X_{Delay})(E1-Y)}(\Delta\tau) \tag{11}$$

3 Performance

3.1 The autocorrelation function

As it is shown in Eq. (10) and Eq. (11), the new correlation function will be the same as the autocorrelation function of PN codes. Several crorrelation function is

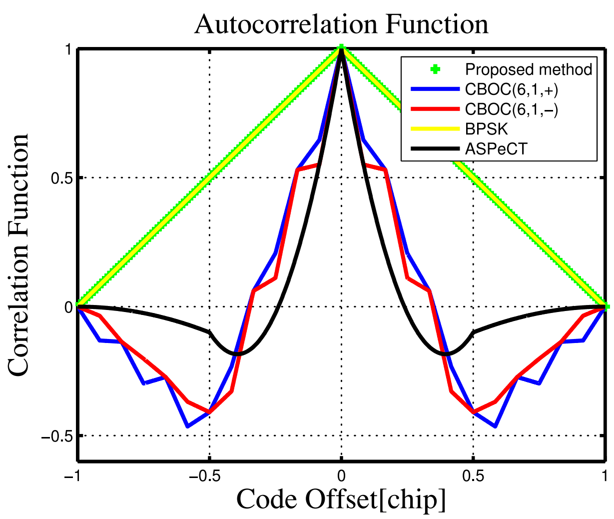


Fig. 4. Comparison of autocorrelation functions.

DOI: 10.1587/elex.11.20140979
Received October 14, 2014
Accepted November 4, 2014
Publicized November 19, 2014
Copyedited December 10, 2014

shown in Fig. 4 [6]. The result will become less sharp than that of CBOC. Thus, the proposed method allows, in energy search, to use bigger code phase step of size than that should be used in ASPeCT. Different code phase steps used in different method are shown in Table I.

Table I. Compare of code searching step

Method	Traditional	ASPeCT	Proposed
Code phase step (chips)	0.17	0.1	0.5

3.2 Probability of detection

The proposed method generates additional noise because of the multiplication operation. In order to improve the signal to noise ratio, the coherent integration time is extended. Monte Carlo method is chosen to simulate the probability of detection of the proposed method. Sample frequency is 62 MHz. Intermediate frequency is 15.58 MHz. The coherent integration time is 5 times of primary code period, that is 20 ms. Receiver Operating Characteristic (ROC) curve is given in Fig. 5.

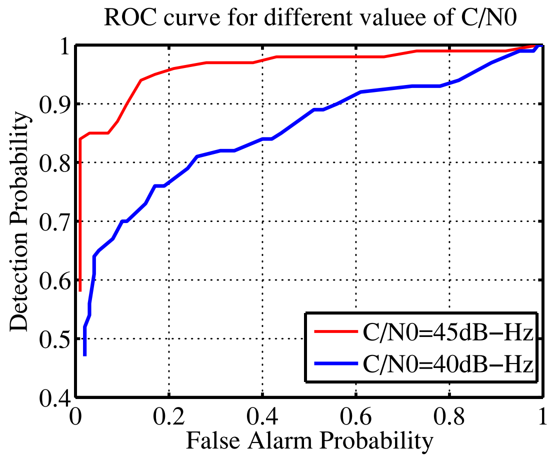


Fig. 5. Probability of detection of proposed method.

3.3 Energy searching issue

Consider the Doppler frequency range that needed to be searched is 10 KHz. It is important to determine the frequency steps needed to cover this 20 KHz range. The maximum step is $2/(3T_{coh})$ [5]. The code of Galileo E1 OS signals is 4 ms long, so it is reasonable to perform the acquisition on at least 4 ms, that is the coherent time. For Galileo E1 OS signal, it is approximately equal to 167 Hz.

As shown above, the proposed method removes the effect of Doppler frequency. Code phase is the first dimension needed to search. The search time of two one-dimension is obviously decreased, compared to that of two-dimension [7]. The total searching time is compared in Table II. For the new correlation function, the code phase bin can be chosen as 0.5 code chip. That will decrease the searching time further.

DOI: 10.1587/elex.11.20140979
Received October 14, 2014
Accepted November 4, 2014
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Copyedited December 10, 2014

IEICE Electronics Express, Vol.11, No.23, 1–7

Table II. Compare of searching time

Method	Traditional	ASPeCT	Proposed
Coherent integration times	1	1	5
Code phase bin (chips)	0.17	0.1	0.5
Code phase number	24070	40920	8184
Doppler frequency bin (Hz)	50	50	50
Doppler frequency number	401	401	401
Total time (sec)	38608.28	65635.68	171.7

For proposed method, the total time

$$T_{total} = (N_{code\ phase} + N_{Doppler\ frequency}) \times T_{coh} \times N_{coh-times} \quad (12)$$

For traditional method, the total time

$$T_{total} = (N_{code\ phase} \times N_{Doppler\ frequency}) \times T_{coh} \quad (13)$$

Further more, the proposed method will consume less hardware resources compared with other unambiguous acquisition method. The BPSK-like method will receive upper sideband and lower sideband separately, and SCPC method will generate in phase and quadrature sub carrier to get rid of the sub carrier. The proposed method just needs some extra multipliers to accomplish unambiguous acquisition. The last but not the least, the acquisition will not be effected even though the change of the Doppler is very big.

4 Conclusion

This paper proposes a novel method to accomplish acquisition of Galileo E1 OS signal, and the performance of this method is analyzed. The signal and delayed signal are separately multiplied by local code and delayed local code. The combination of data and pilot channel will be coherently integrated. Finally two kinds coherent integrations are multiplied, regarded as the decision variable. This method eliminates the side peaks of autocorrelation function, and develops new autocorrelation function with less sharper main peaks than that of CBOC. Even though the multiplication will result in increased noise power, long coherent integration time will compensate for this. Also, the effect of Doppler frequency is removed, that will decrease searching time significantly.

DOI: 10.1587/elex.11.20140979
Received October 14, 2014
Accepted November 4, 2014
Publicized November 19, 2014
Copyedited December 10, 2014