Unambiguous Synchronization Scheme for GNSS BOC(n,n) Signals

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Abstract—Galileo and Modernized GPS have included in their signal structures a new signal modulation: the Binary Offset Carrier (BOC), which multiplies a spreading code with a square wave sub-carrier. It creates a split spectrum with two main lobes shifted from the center frequency by sub-carrier. This modulated signal induces better tracking in white noise and better inherent multipath mitigation compared to the spreading code alone. However, it also makes acquisition more challenging and tracking potentially ambiguous due to its multiple peak autocorrelation function. This paper, instead of trying to find a generic solution, focuses on a specific BOC signal: the BOC(n,n). A novel tracking technique dedicated to BOC(n,n) signals has been developed by using a synthesized local cross correlation function between received BOC signal and local PRN. It completely removes the side-peak threat. Simulation results show that the combined tracking loops can eliminate false lock points. It also reduces the standard tracking deviation error and slightly degrade its probability of detection compared with the standard tracking algorithm.

Index Terms—BOC Modulation; Tracking; Early-Late-Gate; Ambiguity; Probability Detection; Multipath

I. INTRODUCTION

The European Space Agency (ESA) is presently developing a global navigation satellite system (GNSS) called Galileo, which will complement the existing global positioning system (GPS) [1]. The binary offset carrier (BOC) modulation has been adopted for the Galileo project [2], and it has also been considered for GPS modernization [3]. The BOC signal is created by the product of a pseudo random noise (PRN) code and a square wave sub-carrier having each binary ±1 values and represented by BOC(kn, n), where k is a positive integer and means the ratio of the PRN chip duration to the period of the square wave sub-carrier, and n represents the ratio of the PRN code rate to 1.023 MHz. The aims of BOC modulation are twofold: First, compared with BPSK modulation, it enhances the tracking performances in the presence of the multipath and thermal noise. This property is due to its sharper autocorrelation function and a wider spectrum, with the energy concentrated on the edge of the allocated bandwidth (increased Gabor bandwidth). To exploit these advantages, it is essential to synchronize the BOC signals exactly at the receiver. Second it allows the optimal use of available bandwidth for several signals by limiting their superposition. This characteristic is important in that the navigation systems can share the frequency spectrum bands and reduce the inter-correlation effects (GALILEO L1 OS versus GPS C/A) and to enable the fratricide jamming (GPS M-code). However, the drawback of the BOC technique is due to the ambiguity of the autocorrelation function, which induces a complexity in the acquisition phase, and a risk of biased measures while tracking. Clearly, the traditional techniques for the acquisition of a classical BPSK modulated signal have to be revised to avoid missed detection and false tracking. Due to the high positioning accuracy demands for Galileo system, the study of BOC signal tracking technique has great importance for Galileo receiver design.

This paper differs from other approaches by studying an unambiguous tracking specific to BOC(n,n) signals. The choice of the BOC(n,n) is due the significant possibility that it will be used for the GALILEO civil signal BOC(1,1) on the E2-L1-E1 band and BOC(2,2) signal in GALILEO-E1 band. Moreover, there are also discussions to introduce it as a candidate for the GPSIII civil signal on the L1 band [4]. This makes the BOC(n,n) signals particularly interesting to study. It is important to mention that the new technique presented herein may not be optimal for other BOC modulations due to its dedication to BOC(n,n) characteristics. For the sake of simplicity, only BOC(1,1) signals will be studied.

The remainder of this paper is organized as follow. The first part of this paper introduces the characteristics of BOC signals and traditional tracking loop and details the BOC(1,1) tracking ambiguity problem to underline the motivation for this research. Several unambiguous acquisition methods are briefly analyzed and summarized. A new synthesized cross-correlation delay side-peak cancellation algorithm is investigated in the third part. Its acquisition, tracking and inherent multipath mitigation
performance is given through extensive simulations thereafter. Finally, Section V concludes this paper.

II. AMBIGUOUS PROBLEM FOR BOC SIGNALS

The traditional acquisition of DSSS signal has been very well discussed in [5]. The test criterion in the traditional acquisition scheme is given by [6]:

\[ \psi = \sum_{k=0}^{L-1} I_{1,k}^2 + Q_{1,k}^2 \] 

where, \( I_{1,k} \) and \( Q_{1,k} \) are respectively in-phase and quadrature correlators outputs when the local signals employ the same sin-BOC modulated symbol as the received one. \( L \) is the number of non-coherent summations. The sequential approach tests each possible code delay and Doppler values one by one. Once the maximum correlation result is larger than a threshold, detection is declared.

Since there are significant amount of signal energy located at side peaks of BOC autocorrelation function, under the influence of noise and multipath it is quite likely that one of side peak magnitudes exceeds the main peak, and false acquisition will happen. The power ratio of main peak and second peak (in Fig. 1) can be expressed as:

\[ P_{\text{ratio}} = 1 + \frac{1}{M-1} \] 

where, \( M = 2f_s/f_c \) is the BOC modulation order [7], \( f_s \) is the subcarrier frequency and \( f_c \) is the spreading code frequency.

It can be observed from Fig. 1 that, for \( M = 2 \), side peaks are 6 dB weaker than the main peak. But for \( M = 4 \), the gap between the largest side peak and the main peak is only 2.5dB. With increase of \( M \), the difference between the maximum side peak and the main peak decreases, while the false acquisition probability increase. If false acquisition occurs, the code tracking loop will initially lock on the false lock point near the two side peaks (±0.550 chips) for BOC\((n,n)\) signals (in Fig. 2).

Because of the existence of false lock points, once the delay error of BOC\((1,1)\) code exceeds the scope of stability region, it is easy to be locked at wrong position, causing serious ranging error. This ambiguous tracking phenomenon is unacceptable for high precision positioning, and must be eliminated. The existing unambiguous tracking methods can be summarized into the following categories: a. Over-sampled method which consists in over-sampling the code position in order to be sure to find the main peak by energy comparison. Although it could be conceivable for the low ratio signal (e.g BOC\((1,1)\) and BOC\((2,2)\)), it is unsuitable for high ratio signal (typically for BOC\((14,2)\)). b. the Bump-Jumping technique [8], consists in measuring and comparing the received power of adjacent peak with respect to currently tracked peak and jumping left or right depending on the comparison result, until maximum peak is found. c. the BPSK-like technique, This method is firstly proposed by Martin in [9]. It only considers the received BOC\((x,y)\) signal equivalent to the sum of two BPSK\((y)\) signals with carrier frequency symmetrically positioned on each side of the BOC carrier frequency. Thus each lobe is treated independently as a BPSK signal, which provide unambiguous correlation function [10, 11]. The shortage of BPSK-like technique is in that it induces a 3 dB degradation (at least) in signal to noise ratio if applied on a single side lobe (Single Side Band or SSB), due to the correlation losses. although applying on both lobes in parallel (Double Side Band or DSB) [12] or using High order BPSK-like method, the -3 dB loss can be partially compensated, this method is still involves some energy degradation, 0.5db to 0.8db [13]. d. The Sub Carrier Phase Cancellation (SCPC) technique [10, 14]. The basic idea in SCPC is to deal with the sub-carrier in the same way as carrier. In addition to the local in phase and quadrature carrier signals, an in phase and a quadrature local subcarrier signals have to be generated. Thus, two correlation channels are generated here. On one channel, the received filtered signal is correlated with the local BOC signal in sub carrier phase, and on the other one the received filtered signal is correlated with the local BOC signal in sub carrier quadrature. When these two correlation channels are combined, an ACF (Auto-correlation function) similar to the BPSK one is obtained. The mainly defect is that SCPC requires more correlators.

Figure 1. Power ratio of main and second peak

Figure 2. Performance of the discriminator output for BOC\((n,n)\)
Single Side-Lobe Technique. This method is firstly proposed by Fishman and Betz in [12] and related patent is shown in [15]. Only one side-lobe of BOC spectrum is selected and treated because the side-lobe spectrum is similar to that of BPSK modulation.

Side-Peak Cancellation Technique (SPCT) [16, 17]. The essence of SPCT is to remove the side-peaks of BOC auto-correlation function since they are the origin of the false lock tracking points. The flaw of the method ASPeCT [17] is that the side peaks are still exist although the amplitudes are much smaller compared with the traditional method.

After discussion the current proposed unambiguous technique, we knew that these method are designed to general BOC signals, besides ASPeCT (which is only effective to sinBOC(n,n) signals). Although bump-jumping (BJ) technique in tracking process can rectify this false lock, this technique is also based upon magnitude comparison, so it still has a high probability of failure when signal-to-noise ratio is low. And BJ technique needs multiple dwell time to detect and recover from false lock so that it is inapplicable to some critical applications. Therefore, avoiding false acquisition is more desirable than recover from false lock. Other approaches need more correlators and subcarrier generating circuits, which makes the receiver more complexity. In the next section a new unambiguous acquisition and tracking algorithm for BOC(n,n) signals is formulated. The new proposed method is so easy to implement and suitable for acquisition and tracking stage.

### III. PROPOSED CORRELATION FUNCTION

The main idea of the proposed unambiguous tracking technique based is to construct a combined single peak correlation function by combining the early cross-correlation between the received BOC signal and the local PRN code with the late one to remove the undesired side peaks. In this paper, it is assumed that there is a training period for synchronization, i.e. d(t)=1 (since synchronization is more rapid in the absence of data modulation [18]). Then the cross correlation of SinBOC(n,n) and CosBOC(n,n), for an ideal case (no multipaths and ideal PRN code), can be expressed as [19]:

$$R_{\text{sin BOC/PRN}}^{(e-n)}(\alpha) = \frac{1}{2} \left[ \text{Tri}_{\alpha} \left( t - \frac{\epsilon}{2} \right) - \text{Tri}_{\alpha} \left( t + \frac{\epsilon}{2} \right) \right]$$ (3)

And,

$$R_{\text{cos BOC/PRN}}^{(e-n)} = \frac{1}{4} \left[ \text{Tri}_{\alpha} \left( t - \frac{\epsilon}{4} \right) - \text{Tri}_{\alpha} \left( t + \frac{\epsilon}{4} \right) \right]$$ (4)

where,

$$\text{Tri}_{\alpha}(t) = \begin{cases} 1, & \text{for } |t| < \alpha \\ 0, & \text{else} \end{cases}$$

$$\alpha$$ and $$\beta$$ are the center and width of the triangular function respectively. From above formula we can see that the BOC cross-correlation function consists of the sum of triangular function. This is why the BOC autocorrelation function has multiple side-peaks.

In order to find a clue to a solution of the ambiguous problem, let us investigate the property of $$R_{\text{sin BOC/PRN}}(\tau)$$. For $$R_{\text{sin BOC/PRN}}^2(\tau - 0.5)$$ and $$R_{\text{sin BOC/PRN}}^2(\tau + 0.5)$$ are symmetric and have one overlapped peak with respect to $$\tau = 0$$.

From this observation, we can see that the addition and subtraction operations $$R_{\text{sin BOC/PRN}}^2(\tau - 0.5)$$ and $$R_{\text{sin BOC/PRN}}^2(\tau - 0.5)$$ create correlations with two main peaks and two side-peaks and two side-peaks only, respectively, as shown in Fig. 3. Thus, the operation yields a correlation function with a main-peak having the same shape as that of the main-peak of auto-correlation function. Finally, to remove the side-peak, the following combination is performed:

$$R_{\text{in}}^{\text{proposed}} = R_{\text{sin BOC/PRN}}^2(\tau - 0.5) + R_{\text{sin BOC/PRN}}^2(\tau + 0.5)$$

$$- (R_{\text{sin BOC/PRN}}^2(\tau - 0.5) + R_{\text{sin BOC/PRN}}^2(\tau + 0.5))^2$$ (6)

In order to compared with another method proposed in [16] by Korea, its combined correlation function was also drawn in Fig. 3. From Fig. 3, it is clearly shown that the proposed correlation generates a correlation function with no side peaks for SinBOC(n,n) signal. So the proposed correlation function can be performed by the following tracking structure (Fig. 4). From Fig. 4, the procedure of the proposed structure can be clearly understood. Firstly the received BOC signal is multiplied with the locally generated and ±0.5 chips delayed PRN code, and then down converted to baseband in-phase (I) and quadrature phase (Q) signals. Then the correlating algorithm between BOC signal and delayed PRN code is executed through the integration and dump procedure. Finally, combined the delayed correlation, a novel correlation function with no side peaks can be obtained through the following operation:

$$R_{\text{in}}^{\text{proposed}} = \left[ R_{\text{in}}^i(\tau + 0.5) \right]^2 + \left[ R_{\text{in}}^o(\tau + 0.5) \right]^2$$

$$+ \left[ R_{\text{in}}^i(\tau - 0.5) \right]^2 + \left[ R_{\text{in}}^o(\tau - 0.5) \right]^2$$

$$- \left[ R_{\text{in}}^i(\tau + 0.5) + R_{\text{in}}^o(\tau - 0.5) \right]^2$$

$$- \left[ R_{\text{in}}^o(\tau + 0.5) + R_{\text{in}}^i(\tau - 0.5) \right]^2$$ (7)

Unlike ASPeCT, the proposed technique is also suitable for the cosBOC(n,n) signals. We need not to change the acquisition and tracking loop structure, but to change the PRN delay to ±0.75 chips (in Fig. 5). So it can get the same tracking structure from the operation (9) and (10):
is the difference between the frequency of the local reference code shift \( \Delta f \) and the local carrier and the incoming carrier, \( \varepsilon_\theta \) is the difference between phases of the local carrier and of the incoming signal carrier, \( n_1(t) \) and \( n_2(t) \) are the In-phase and Quadrate baseband equivalent noises of the received noise that are assumed to be Gaussian, independent and with a constant bilateral PSD equal to \( N_0/2 \) (well known properties based on Rice decomposition of white noise), and \( x(t) \) is the BOC signal composed of a pseudo-random noise (PRN) modulated by a square subcarrier to form a BOC(m,n) signals. After carrier wipe-off and correlation, the correlators outputs are as follows:

\[
\begin{align*}
I_1(k) &= \sqrt{C} d(k) R_{c_{\text{BOC}/PRN}}(\varepsilon_1) \cos(\varepsilon_1) + n_{i_{\text{BOC}/PRN}}(k) \\
Q_1(k) &= \sqrt{C} d(k) R_{c_{\text{BOC}/PRN}}(\varepsilon_1) \sin(\varepsilon_1) + n_{q_{\text{BOC}/PRN}}(k)
\end{align*}
\]

Consequently, a new DLL architecture based on the previous correlation functions (7) and (8) can be proposed. Now that the proposed tracking principles have been explained in detail and its unambiguous property has been shown, it is important to study the impact of the main sources of error on the code acquisition and tracking performance to ensure that it does not imply significant drawbacks. As a consequence, the probability of detection, the effect of thermal noise and multipath performance are investigated in the following section.
and n_q are the unfiltered White Gaussian noise, R_{\text{BOC/PRN}}(\epsilon_i) is the cross-correlation between the local reference PRN code and the filtered incoming BOC code, n_{\text{BOC/PRN}}(k) and n_{\text{BOC/PRN}}(k) are centered Gaussian correlator output. Now we will utilize this signal model to study the detection performance of this proposed unambiguous acquisition technique.

### A. Probability of Detection

The qualities of an acquisition scheme are measured in terms of false alarm probability (P_f) and of detection probability (P_d) [20].

\[ P_f = \int_{\text{Thr}}^{\infty} P_n(x) dx \]  
\[ P_d = \int_{-\infty}^{\text{Thr}} P_n(x) dx \]  

where, \( P_n(x) \) is the probability density function (PDF) for noise with no signal present, has a zero-mean, and \( P_n(x) \) the PDF for noise with the signal present, has a non-zero-mean. The acquisition threshold Thr is usually based on an acceptable probability of false alarm \( P_f \). A detailed description of the spread spectrum signal acquisition can be found in [21]. Based on that theory and on (7), the statistical test proposed for the acquisition scheme based on the proposed receiver structure is:

\[ Z_d = \sum_{k=0}^{L-1} \left[ I_{\text{BOC}}(k) + \frac{Q_{\text{BOC}}(k) + Q_{\text{BOC}}(k)}{2} \right] + \frac{Q_{\text{BOC}}(k)}{2} \]

According to the statistical theory [22], we know that the test criterion expressed in (14) is a sum of chi-square variables with 2L degree of freedom (DOF) (the first two terms are non-central and the second one is central) follows \( \chi^2 \) distribution with 2L degrees of freedom as:

\[ P_d(x) = \frac{1}{2\pi} \left( \frac{\lambda}{\lambda} \right)^{\lambda/2} e^{-\lambda/2} I_{\text{BOC}} \left( \frac{\lambda \sqrt{x}}{\lambda} \right) \]

where, \( \alpha^2 \) is the variance of the statistically independent Gaussian distributed noise, \( I_{\text{BOC}}(x) \) is the \( \alpha \) th-order modified Bessel function of the first kind. The non-centrality parameter \( \lambda \) for the first term and the variances of the test criterion for first and second term are:

\[ \lambda = L \cdot \text{CNR} \cdot T_p \left( R_{\text{BOC}}(\epsilon_i) + R_{\text{BOC}}(\epsilon_i) \right) \]

\[ \delta_i^2 = 2L \cdot \text{CNR} \cdot T_p \left( R_{\text{BOC}}(\epsilon_i) + R_{\text{BOC}}(\epsilon_i) \right) \]

where, \( T_p \) is coherent integral time, \( \epsilon_i \) is the PRN code phase error, and \( \text{CNR} \) is the carrier to noise ratio, \( R_{\text{BOC}} \) is the autocorrelation function of local generated signals. \( R_{\text{BOC}} \) is the cross-correlation function between received BOC signals and local generated early or late PRN code. Note that the correlation values and the noise power have been normalized. The distribution of the two terms of the test criteria is independent owning to the fact that the noise coming from \( R_{\text{BOC}} \) and \( R_{\text{BOC}} \) are independent proved in [23]. Moreover, according to the statistic theory, the distribution of the sum of independent variables is a convolution between the distributions of these random variables. And the mean value is the sum of the mean value of these independent random variables. Consequently, the variance is the sum of the variances of these random independent variables. Here, it is assumed no code delay and no Doppler error. Because of the complexity and inconvenient to compute the theoretical value \( P_d \), \( P_f \) and the central limit effect, the distributions of both sum and difference tend to be closer to the normal than the original parent distributions, Marcum’s Q-function is always be used to approximate calculation. So we have:

\[ P_d(\text{Thr}) \approx \frac{1}{2} \left( 1 + Q \left( \frac{\sqrt{\text{Thr} - \mu}}{\sqrt{\sigma^2 + \delta_i^2}} \right) \right) \]
B. Thermal Noise on Estimated Code Phase

The method to derive the power of the noise on the estimated code phase provided by a DLL has been calculated in [23][24] for the BPSK case. The same method can be applied for the BOC modulation. The variance of the error of synchronization expressed in squared units of chips is finally given by:

$$\delta^2_e = E\left[\frac{2B_c T_p R_s(0)}{(KT)^2}\right]$$

(19)

Now, the variance of the error for the proposed DLL discriminators can be derived.

The expression of the error signal provided by the Early-Minus-Lately power (EMLP) discriminator is formula (21).

$$V_{EMLP} = \begin{pmatrix}
I_c^2 (\tau + 0.5) \\
I_c^2 (\tau - 0.5) \\
+Q_e^2 (\tau + 0.5) \\
+Q_e^2 (\tau - 0.5)
\end{pmatrix}
- \begin{pmatrix}
I_c (\tau + 0.5) \\
+I_c (\tau - 0.5) \\
+Q_e (\tau + 0.5) \\
+Q_e (\tau - 0.5)
\end{pmatrix}
+ \begin{pmatrix}
I_c^2 (\tau + 0.5) \\
I_c^2 (\tau - 0.5) \\
+Q_e^2 (\tau + 0.5) \\
+Q_e^2 (\tau - 0.5)
\end{pmatrix}
- \begin{pmatrix}
I_c (\tau + 0.5) \\
+I_c (\tau - 0.5) \\
+Q_e (\tau + 0.5) \\
+Q_e (\tau - 0.5)
\end{pmatrix}$$

(20)

The terms in first bracket are the true signal. This term allows to derive the gain (or the slope) of the discriminator. The slope of the proposed DLL discriminator close to the lock point is the derivative of the terms in first bracket at the zero point, so we can get:

$$K = CT_c^2 \begin{pmatrix}
R_c^2 (\epsilon + 0.5 + \delta T_c) \\
+R_c^2 (\epsilon - 0.5 + \delta T_c) - R_c^2 (\epsilon + \delta T_c) \\
-R_c^2 (\epsilon + 0.5 - \delta T_c) \\
+R_c^2 (\epsilon - 0.5 - \delta T_c) - R_c^2 (\epsilon - \delta T_c)
\end{pmatrix} = \frac{4CT_c^2 (1-d)}{T_c}$$

(21)

And for Korea’s method [16], the gain of the discriminator is:

$$K_{EMLP} = -\frac{4CT_c^2 (1-d)}{T_c}$$

(22)

where, d is the early-minus-late spacing. From the noise terms in the EMLP discriminator and for convenience on calculations, we will assume that the error is close to the lock point $\varepsilon \approx 0$, so we can get the variance of the proposed method as:

$$R_s(0) = 2CN_0 T_p (1-d)^2 \left(1 + \frac{2}{C N_0 (1-d) T_p}\right)$$

(23)

The theoretical variance of the error of synchronization expressed in squared units of chips for the sinBOC(n,n) EML Power DLL that is (after simplifications):

$$\delta^2_{\text{EMLP}(n,n)} = \frac{B_c d}{C N_0 (2-3d) T_p}$$

(24)

For comparison, the tracking error variance of traditional EMLP discriminator in thermal noise for the sinBOC(n,n) is given by [25]:

$$\delta^2_{\text{EE}(n,n)} = \frac{B_c d}{C N_0 (2-d) T_p}$$

(25)

And for BPSK-like method is given by [25]:

$$\delta^2_{\text{EE}(n,n)} = \frac{B_c d}{C N_0 (2-d) T_p}$$

(26)

As a confirmation of the calculation, (25) follows closely the results obtained in [26] for a pure BOC tracking. Equations (24) and (25) show that the formula of tracking techniques is very similar and the tracking error for the proposed technique are slightly higher than the traditional one. In order to understand the performance of the proposed method, several figure are plotted to compare the theoretical code tracking standard deviation of the proposed tracking technique with the traditional and BPSK-like tracking methods for sinBOC(n,n) signals under different integration time (Tp=1ms or 8 ms) and different tracking space (d=0.1 or 0.05 chips). From Fig. 8 (Tp=1ms, d=0.1), it can also find that the tracking degradation phenomenon of the proposed technique caused by multiplicative noise will have a noticeable impact only at very low CNR(<30dB). The low level degradation shows excellent behavior of the proposed method. It is important to note that the difference
between the two tracking error standard deviations is not very dependent upon the chip spacing $d$ or the coherent integration time ($T_p$) when the CNR is larger than 35dB. In order to test the improvement of the proposed technique for general BOC signals, we compare the theoretical code tracking standard deviation of the proposed technique with the traditional tracking method for $\sin BOC(n, n)$ signals under the integration time ($T_p=1\text{ms}$) and tracking space ($d=0.1\text{ chips}$) in Fig. 8 and the integration time ($T_p=8\text{ms}$) and tracking space ($d=0.05\text{ chips}$) in Fig. 10 respectively. From the two figures, we notice an interesting phenomenon that the standard deviation of proposed technique for $\sin BOC(n, n)$ have smaller tracking error at every CNR Compared with traditional tracking method at same Early-Late spacing and non-coherent integration Time. We can clearly see the improvement in Fig. 10. Under the condition of $T_p=1\text{ms}$ and $d=0.05\text{ chips}$, the standard deviation error of the proposed tracking technique have a smaller degradation compared with the traditional one at CNR>30dB. The degradation is only in lower CNR conditions and its degradation maximum is smaller than 4.5dB. So we can safely get the conclusion that the proposed receiver still has a good performance when CNR>30dB. In addition, we can solve the degradation at lower CNR by increasing multiple integration time and decreasing tracking spacing.

![Figure 7. Comparison of the Theoretical Traditional and Proposed Code Tracking Error Standard Deviation](image1)

![Figure 8. Comparison of the Theoretical Traditional and Proposed Code Tracking Error Standard Deviation](image2)

![Figure 9. Comparison of the Theoretical Traditional and Proposed Code Tracking Error Standard Deviation](image3)

![Figure 10. The degradation of proposed technique compared with traditional tracking method](image4)

V. CONCLUSION

In this paper, the ambiguous tracking problem is analyzed for classic early-late-gate tracking loop and some other unambiguous approaches are presented and compared. To resolve the ambiguous problem, a new correlation function is proposed and simulated for $\sin BOC(1,1)$ signal. Simulation results show that, unlike the other correlation and BOC autocorrelation function, the proposed correlation function does not have any side-peaks, so it can eliminate false lock points and it is also
applicable to BOC(n,n) and cosBOC(n,n) signals. The detection performances of the proposed tracking loop have been analyzed and compared with that of the traditional and Korea’s method. Although the numerical results show that the proposed technique has a slightly degradation in acquisition and tracking stage, it can perfectly eliminate false lock points which make the receiver more robust than traditional one. So it can be considered to be a good choice for implementing the Galileo BOC(1,1) receiver. Although this paper is based on SinBOC(1,1), it can be conveniently extended to SinBOC(n,n) and cosBOC(n,n).

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