International Journal of Current Advanced Research
ISSN: O: 2319-6475, ISSN: P: 2319 – 6505, Impact Factor: SJIF: 5.995
Available Online at www.journalijcar.org
Volume 6; Issue 4; April 2017; Page No. 3419-3424
DOI: http://dx.doi.org/10.24327/ijcar.2017.3424.0285

Research Article

OFFLINE IMPLEMENTATION OF SUBCARRIER TRACKING TECHNIQUE FOR BOC MODULATED SIGNALS IN SATELLITE NAVIGATION

Pravin Patidar[1]., S C Bera[1] and Anuj Vaniya[2]

[1]Space Applications Centre, ISRO, Ahmedabad, India
[2]ADIT, VV Nagar, Anand, India

A R T I C L E I N F O

Article History:

Received 20th January, 2017
Received in revised form 19th February, 2017
Accepted 22nd March, 2017
Published online 28th April, 2017

Key words:

xxxxxx

A B S T R A C T

Tracking of Binary Offset Carrier (BOC) signal is more challenging than Binary Phase Shift Keying (BPSK) signal, due to multiple peaks in autocorrelation function. Offline processing of the BOC signal is carried out using offline software receiver. In this work it is proposed to track subcarrier, code and carrier of BOC signal using only two loops Phase Lock Loop (PLL) and Delay Lock Loop (DLL) which reduces number of correlators as compared to double estimator, bump jumping and Astrium correlator method. The tracking performance of the proposed method is analysed using BOC (5,2) signals.

Copyright©2017 ***Pravin Patidar et al.*** *This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.*

INTRODUCTION

Satellitebased navigation systems provide positioning, navigation and timing services to the users over a defined service area. The overall system generally consists of three segments: Space Segment, Control Segment and User segment. The space segment consists of satellite constellation carrying navigation payloads, which transmit navigation signals over multiple frequency bands. The ground segment consists of major systems for controlling the satellite constellation, generating navigation data and maintaining system time. The user segment consists of variety of receivers supporting different classes of users and applications.

In recent years, Global Navigation Satellite System (GNSS) have been developing rapidly. The frequency spectrum allocated for navigation is becoming more and more crowded. To reduce interference among different navigation signals while utilizing the same frequency band new modulation technique called as Binary Offset Carrier (BOC) modulation is introduced for GNSS system. A BOC modulation multiplies PRN code with a square wave subcarrier which creates a split spectrum with two main lobes shifted from the centre frequency by the frequency of the subcarrier. Benefit from the modulation of subcarrier, the Binary Offset Carrier (BOC) modulated signal, which has been used in GNSS which avoids interferences and improves frequency spectrum utilization significantly.

*Corresponding author: **Pravin Patidar**
Space Applications Centre, ISRO, Ahmedabad, India

Figure 1 shows different types of GNSS receiver. In Hardware receiver, all process (acquisition, tracking, data demodulation, etc.) is done using hardware only where in software defined receiver up to correlation of incoming signal to replica signal is done using hardware then further process in software. There are two types of software receiver namely real time software receiver and offline software receiver. We have done an offline processing for signal organization because we can test the same captured signal multiple times in same scenario. Offline processing is used for signal processing versatility. In one aspect, we can predict the error of our algorithm by testing the stored signal multiple times in the same dynamic scenario and also compare to other available algorithms.

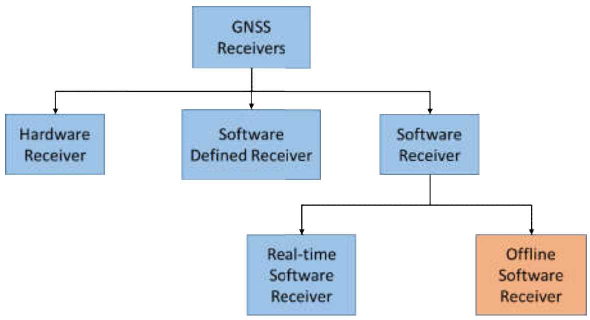

Figure 1 GNSS Receivers

Binary Offset Carrier Modulation

The complex envelope of BOC signal can be expressed as:

$$s(t) = e^{-i\theta} \sum_{k} d_k c_{T_s}(t-\tau) \cdot sc_{T_s}(t-\tau) \qquad (1)$$

Where, d_k is the data-modulated spreading code unit, $sc_{T_s}(t)$ is the subcarrier which is a square wave and a periodic function with period $2T_s$. $c_{T_s}(t)$ is the spreading code which is also called as Pseudo Random Number (PRN).

Figure 2 shows the block diagram of BOC signal generation. Subcarrier chip rate is:

$$f_{sc} = m \cdot 1.023\ MHz \tag{2}$$

Code chip rate is:

$$f_c = n \cdot 1.023\ MHz \tag{3}$$

BOC(m,n) defines the chip rate of subcarrier and code. And Figure 3 shows the time and frequency domain representation of PRN code Subcarrier and Baseband BOC (5,2) signal. It shows that the spectrum of the BOC signal lies within a bandwidth less than 20 MHz.

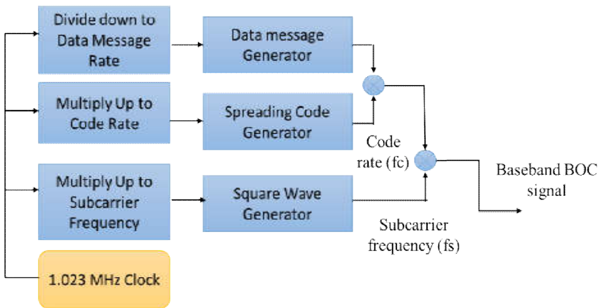

Figure 2 Block diagram of BOC baseband signal generation

For BOC (5,2) signal subcarrier and code chipping rate will be 5.115 MHz (5*1.023 MHz) and 2.046 MHz (2*1.023 MHz) respectively. The autocorrelation function of BOC (5,2) has multiple peaks in correlation output. The number of peaks can be determined as $\left(\frac{4m}{n}\right) - 1$ [1].

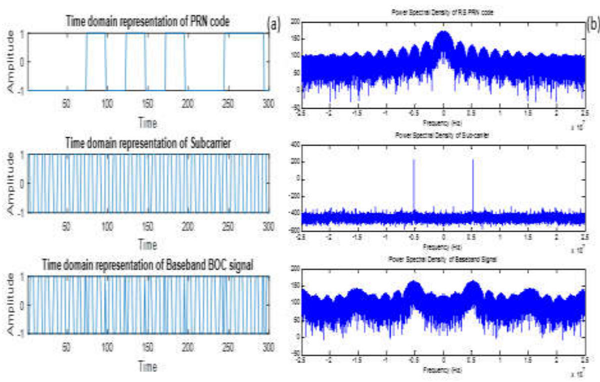

Figure 3 (a) Time domain representation (b) Frequency domain representation of PRN code Subcarrier and Baseband BOC signal respectively

As shown in Figure 4 there will be 9 peaks in acquisition output of BOC (5,2) signal. These peaks are generated because of the subcarrier.

Offline Processing Setup

GNSS Antenna receives the navigation signal which will pass through Low Noise Amplifier (LNA) having the gain of approximately 30 dB.Power supply is applied to LNA and RF amplifiers via Bias T. A band pass filter is used to pass frequencies within the band while reject all other frequencies.

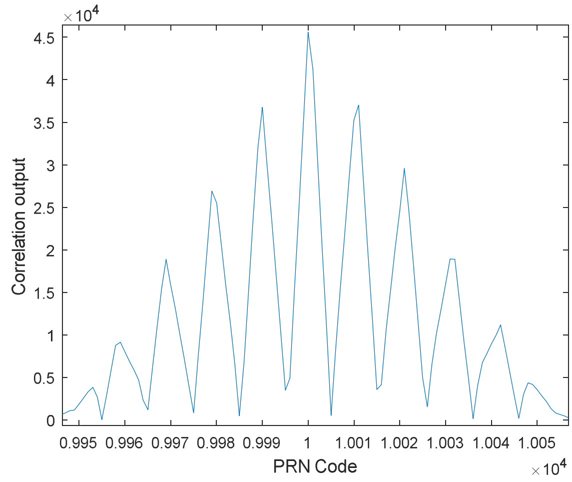

Figure 4 Cross-correlation of BOC signal

Signal generator is used as Local Oscillator (LO) to generate the desired frequency to get intermediate frequency. Low pass filter is required to pass low frequencies within the band while rejecting all higher frequencies. After filtering, sampling and quantization the signal will be stored in high speed memory. Figure 5 shows block diagram of L-band GNSS offline processing set-up which we have implemented.

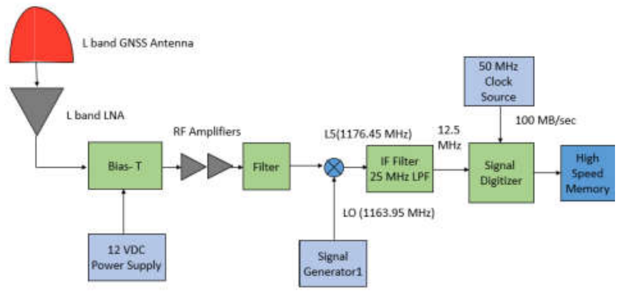

Figure 5 Offline Processing Setup

Acquisition of BOC (5,2) signal

Acquisition is used to find initial code phase and carrier frequency. There are basically three methods for acquisition [2].

1. Serial Search Acquisition
2. Parallel Frequency Space Search Acquisition
3. Parallel Code Space Search Acquisition

Use of FFT algorithm in parallel code space search acquisition reduces computational complexity compared to other methods. For BOC (5,2) signal, to generate replica signal at the receiver subcarrier is multiplied with PRN code and this new spreading code is multiplied with IF.

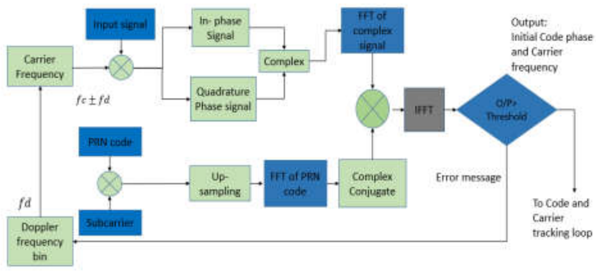

Figure 6 Block diagram of Parallel Space Search Acquisition of BOC (5,2) signal

In acquisition, fast Fourier transform of received signal multiplied conjugate of fast Fourier transform of locally generated replica signal and then inverse Fourier transform will give correlation output as shown in figure 6.

The correlation output will give maximum peak at starting point of PRN code and carrier frequency of the signal. This technique is based on a property of cross-correlation of Fast Fourier Transformation(FFT) which is given by,

$$y(n) = \frac{1}{N}\sum_{m=0}^{N-1} r^*(n)a(n-m) \qquad (4)$$

$$a(n) = c(n) \cdot sc(n) \qquad (5)$$

Where, $r^*(n)$: received signal multiplied with complex carrier signal in time domain; $c(n)$ is PRN code and$sc(n)$is subcarrier.

Equation no. (4) is the cross correlation of the two sequences r(n) and a(n), and according to cross-correlation property of Fourier Transform we can write that,

$$Y(k) = R^*(k)A(k) \text{ or } Y(k) = R(k)A^*(k) \qquad (6)$$

Where, R(K): Fast Fourier transform of r(n).
A(K): Fast Fourier transform of a(n).

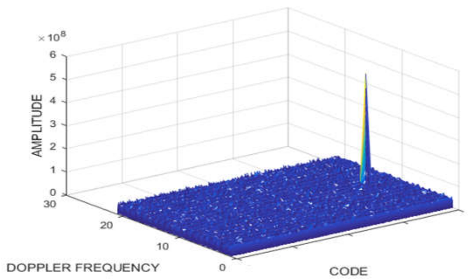

Figure 7 Correlation output for all Doppler frequency bins

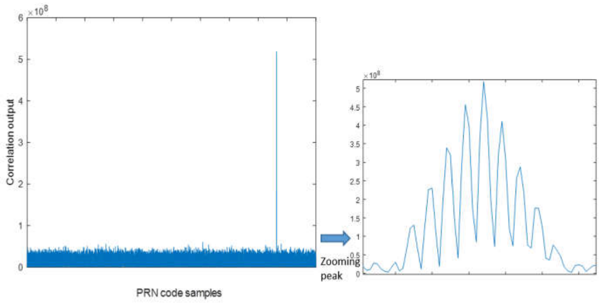

Figure 8 Output of Acquisition of BOC (5,2) signal

The output of the cross correlation will give a peak at the best match of input signal with the replica signal. If peak value is not above threshold, then according to Doppler frequency-bins carrier frequency will change and same process will be repeated as shown in figure 6. Figure 7 shows the correlation output for all Doppler frequency bins. PRN code value indicates the starting point of PRN code or code phase of the signal. The Correlation output of Doppler frequency bin where the peak is above threshold is shown in figure 8. After zooming the peak, it is found that there are multiple peaks in the output because of the subcarrier component in the input signal. The initial code phase and carrier frequency is applied to tracking loop.

BPSK and BOC Signal Tracking Methods

For GNSS receivers signal must be as clear as possible. The local spreading code and carrier must be well aligned with the incoming signal. To find fine carrier frequency and code phase and to keep it aligned with the input signal tracking isnecessary.

Overview of BPSK signal tracking

After acquisition of received signal initial code phase of the PRN code and initial carrier frequency will be the input of the tracking loops. There are mainly two tracking loops used Phase locked loop or Frequency Lock Loop (PLL or FLL) [4] for carrier tracking and Delay Lock Loop (DLL) for code tracking. Figure 9 shows the block diagram of BPSK signal tracking.

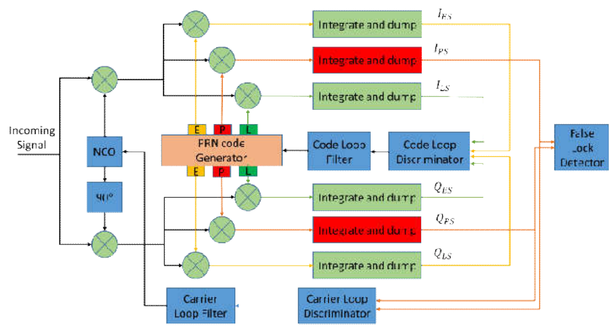

Figure 9 Block diagram of compelete tracking channel of BPSK signal

Three PRN code replicas early late and prompt are correlated with in phase and quadrature phase component of the signal and integrated. Early late spacing for DLL will be 0.5 chip.

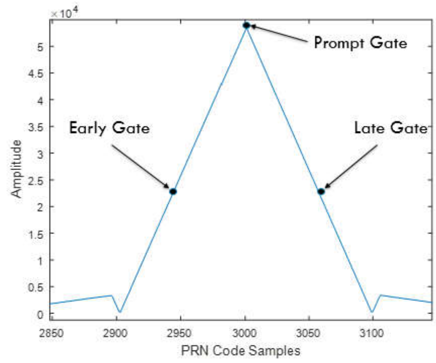

Figure 10 Highest peak in the acquisition output

Code loop descriminator computes code error by taking difference of early and late power. Figure 10 shows the highest peak in the acquisition output, when code loop discriminator output will be zero, prompt gate will be on the main peak and DLL will be locked. Carrier loop descriminator computes carrier error which is filtered out and given to the numerically controlled oscillator (NCO) [3].

VE-VL or bump jumping

Very Early- Very Late or bump jumping BOC tracking technique monitors the amplitude of adjacent peaks which was derived and implemented by P. Fine and W. Wilson. The comparison of prompt with VE and VL is carried out. If amplitude of prompt is larger, then either VE or VL tracker will jump in direction of $+T_s$ and If amplitude of VE and VL is larger, then prompt tracker will jump in direction of $-T_s$.

The prompt, VE and VL amplitudes are from In-phase component. It is assumed that in code tracking loop prompt, VE and VL are working properly and all quadrature components are nearer to zero. If it is not then comparison can be computed among $I_p^2 + Q_p^2$, $I_{VE}^2 + Q_{VE}^2$ and $I_{VL}^2 + Q_{VL}^2$. Front end filtering, multipath and group delay distortion degrade the performance of the receiver. In the unavoidable presence of white noise creates fluctuation in amplitude of peaks, there is a possibility of a miss-correction [5].

The Double Estimator

The new approach for BOC tracking is double estimator method developed by M. Stephen Hodgart and Paul D. Blunt. There are three independent tracking loops are used to track BOC signals namely Subcarrier Lock Loop (SLL), Delay Lock Loop (DLL) and Phase or Frequency Locked Loop (PLL or FLL). All loops having independent loop filters are able to track subcarrier, code and carrier. This method is more computationally complex [6].

Astrium Correlator

Astrium Correlator method uses two independent but co-operative Phase (or Frequency) Lock Loop (PLL or FLL) and Subcarrier Lock Loop (SLL) otherwise it is similar as Double Estimator. Complexity wise this method lies between bump jumping and double estimator method [7].

Proposed method for BOC tracking

As compare to BPSK signal, there is more possibility of false lock of the loop while tracking BOC signal because of multiple peaks in the correlation output as shown in figure 10. The proposed BOC tracking method uses only two loops Delay lock loop (for subcarrier and code tracking) and Phase (or Frequency) Lock Loop. The enhanced version of PLL is Costas Loop is implemented which is insensitive to 180° phase shift.

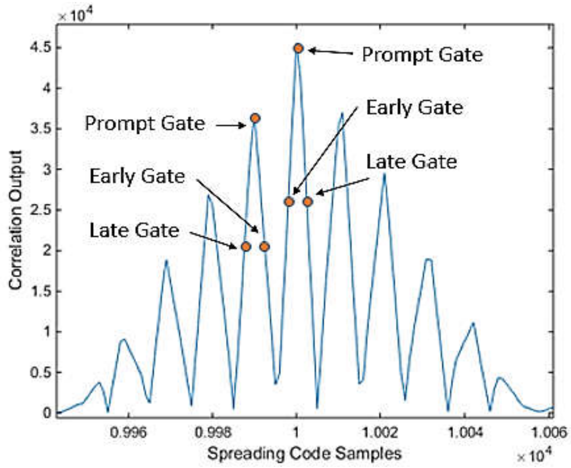

Figure 11 False lock due to multiple peaks

As shown in figure 11 during tracking of BOC modulated signal due to multiple peaks in correlation function, there is more possibility to lock DLL on another peak except the main peak which is called as false lock.

Tracking of BPSK signal can be done by ± 0.5 chip early and late spacing of the code for DLL. In BOC (5, 2) modulated signal 9 peaks are produced within the chip of main peak in correlation output. So, there is high possibility of false lock as compare to BPSK. These 9 peaks are generated due to subcarrier which is a square signal. In our algorithm, if acquisition of the signal is done on the main peak with sufficient fine resolution of code phase then code phase of the signal is found correctly. If an acquisition output is confinedwithin the main peak of theBOC signal correlation function,then tracking can directly be initiated.Once tracking is started on peak it will avoid the false tracking on side peaks. This method is particularly suitable for offline implementation. The block diagram of BOC signal tracking is shown in Figure 12.

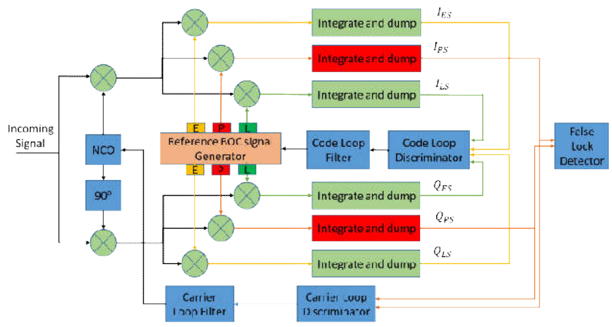

Figure 12 Block Diagram of BOC (5,2) tracking signal

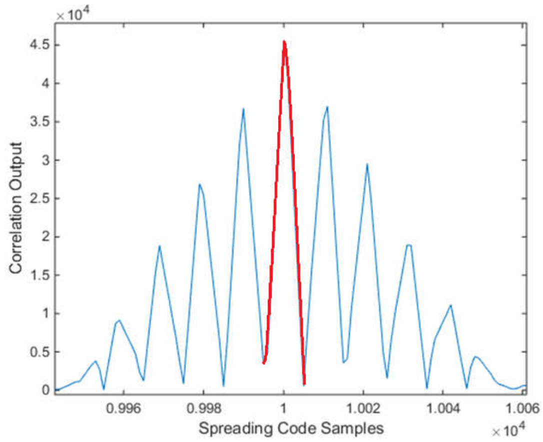

Figure 13 Code and Subcarrier tracking within main peak band.

So, as shown in figure 13 we aretracking right at the main peak of correlation function. For BOC modulated signal first step is multiplying the PRN code with the subcarrier and generate new spreading codes.

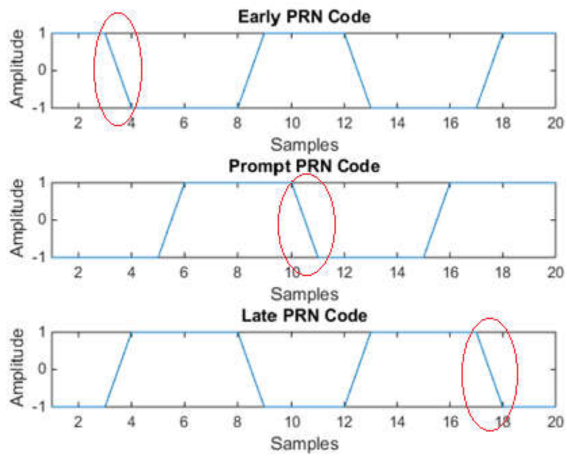

Figure 14 Early-Late spacing of 0.1 chip

These spreading codes are applied to Delay Lock Loop. So tracking of combined subcarrier and code using Delay Lock Loop early-late spacing of the spreading codes will be of ± 0.1 chip, as shown in Figure 14.

Spreading code which is the multiplication of PRN code with subcarrier is given in equation (7).

$$SPC(t) = c(t) \cdot sc(t) \quad (7)$$

In-phase and Quadrature-phase Integrator equations for early, prompt and late can be derived as:

$$I_{ES} = \int_{t=0}^{m} r(t) \cdot \cos\left(2\pi(f_{IF} \pm f_d)t + \theta\right) \cdot SPC(t - \tau_0) \quad (8)$$

$$I_{PS} = \int_{t=0}^{m} r(t) \cdot \cos\left(2\pi(f_{IF} \pm f_d)t + \theta\right) \cdot SPC(t) \quad (9)$$

$$I_{LS} = \int_{t=0}^{m} r(t) \cdot \cos\left(2\pi(f_{IF} \pm f_d)t + \theta\right) \cdot SPC(t + \tau_0) \quad (10)$$

$$Q_{ES} = \int_{t=0}^{m} r(t) \cdot \sin\left(2\pi(f_{IF} \pm f_d)t + \theta\right) \cdot SPC(t - \tau_0) \quad (11)$$

$$Q_{PS} = \int_{t=0}^{m} r(t) \cdot \sin\left(2\pi(f_{IF} \pm f_d)t + \theta\right) \cdot SPC(t) \quad (12)$$

$$Q_{LS} = \int_{t=0}^{m} r(t) \cdot \sin\left(2\pi(f_{IF} \pm f_d)t + \theta\right) \cdot SPC(t + \tau_0) \quad (13)$$

Where, $c(t)$ is PRN code, $sc(t)$ is the subcarrier and multiplication of code and subcarrier gives new spreading code $SPC(t)$. $r(t)$ is the received signal. E-L chip spacing for new spreading code will be 0.1 chip for BOC(5,2) signals here denoted as τ_0 which is multiplied with In-phase and Q-phase signal. I_{ES},I_{PS},I_{LS} is the In-phase early prompt and late integrated output and Q_{ES},Q_{PS},Q_{LS} is the Quadrature-phase early prompt and late integrated output.

Figure 8 shows the early late spacing of spreading code for BOC (5,2) modulated signal. The spreading code phase error of DLL or spreading code loop discriminator output can be derived as [3]:

$$Code\ Error = \frac{1}{2}\frac{E - L}{E + L} \quad (14)$$

Where, E is early power derived as $E = I_{ES}^2 + Q_{ES}^2$ using equation no.(8) and (11) and L is late power derived as $L = I_{LS}^2 + Q_{LS}^2$ using equation no.(10) and (13). As shown in equation (14) whenever early and late amplitude will be equal code error will be zero which will generate zero feedback to the PLL and PLL will be locked.

Using equation no. (9) and (12) the carrier frequency error of Costas Loop or carrierloop discriminator can be derived as [3]:

$$Carrier\ Error = Atana(Q_{PS}/I_{PS}) \quad (15)$$

As shown in table 1 the number of correlators used in proposed method is less than the other methods.

RESULTS AND DISCUSSION

The proposed method is implemented in MATLAB and validated by software simulated signals. The BOC (5,2) signal as transmitted by Indian Regional Navigation Satellite System (IRNSS) satellite is captured for offline processing.Figure 15 Shows the In-phase correlation output and figure 16 Quadrature-phase correlation output as discussed in above section. Figure 17 shows the normalized code loop discriminator output. Figure 18 shows the normalized carrier loop discriminator output.

Table I Number of Correlators used in Various BOC Tracking Method

Tracking method	Number of Correlators
Bump- Jumping method	12
The Double Estimation method	10
Astrium Correlator	10
Proposed method	6

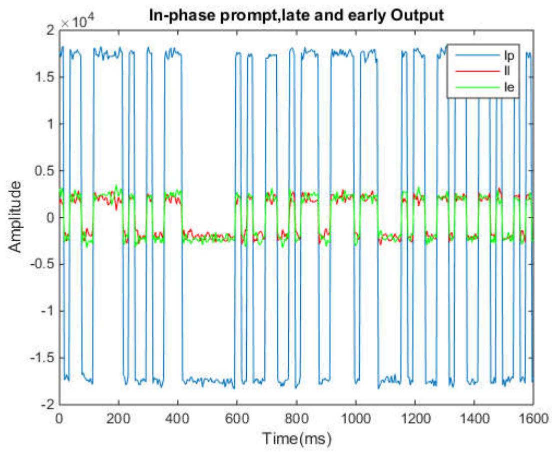

Figure 15 In-phase early, late and prompt correlator output

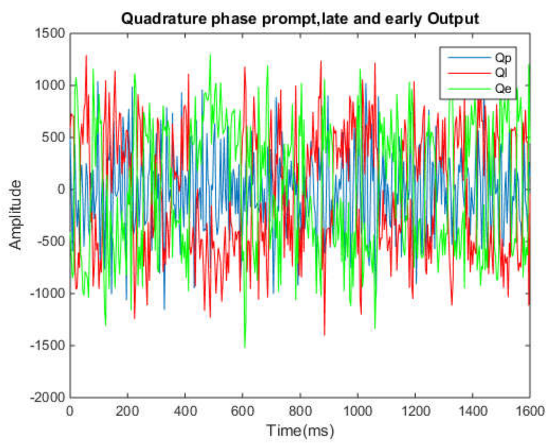

Figure 16 Quadrature-phase early late and prompt correlator output

CONCLUSION

BOC signals have higher tracking accuracy and better multipath rejection. The proposed method is demonstrated with live BOC (5, 2) signal of the IRNSS satellites. In the proposed method the number of correlators is reduced compared to Double Estimator, Bump Jumping and Astrium

Correlator method.

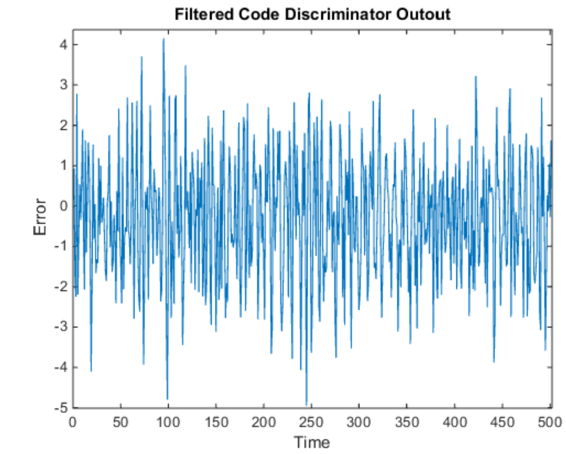

Figure 17 Code Loop Discriminator Output

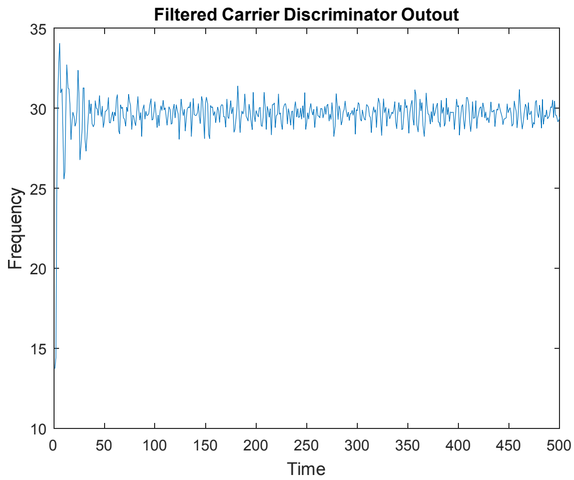

Figure 18 Carrier Loop Discriminator Output

Tracking of BOC (5, 2) modulated signal is implemented using only two loops DLL and PLL in MATLAB. This tracking method is being incorporated in an offline software receiver to evaluate the positioning performance.

References

1. Betz, John W., "Binary Offset Carrier Modulations for Radionavigation", *NAVIGATION, Journal of The Institute of Navigation*, Vol. 48, No. 4, Winter 2001-2002, pp. 227-246.
2. Lin, D., Tsui, J., “Acquisition schemes for software GPS receiver,” *ION GPS-98, pp.* 317-325, Nashville, TN, September 15-18, 1998.
3. P. Ward, “Satellite signal acquisition and tracking,” *in Understanding GPS: Principles and Applications*, E. Kaplan, Ed. Boston: Artech House, 1996, ch. 5, pp. 119-208
4. R.E. Best, Phase Locked Loops: Theory Design and Applications, McGraw Hill, 2007.
5. Frank M. Schubert and Jan Wendel, “BOC Tracking Using Phase and Sub-Carrier Locked Loops”*6th European Workshop on GNSS Signals and Signals Processing,* At Neubiberg, Germany, 2013.
6. M. Hodgart, P. Blunt, and M. Unwin, “The optimal dual estimate solution for robust tracking of binary offset carrier (BOC) modulation,” Fort Worth, TX, USA, 2007.
7. Frank M. Schubert, Jan Wendel, Matthias S¨ollner, Melanie Kaindl, and Rudolf Kohl, “The Astrium Correlator: Unambiguous Tracking ofHigh-Rate BOC Signals”

How to cite this article:

Pravin Patidar *et al* (2017) ' Offline Implementation Of Subcarrier Tracking Technique For Boc Modulated Signals In Satellite Navigation', *International Journal of Current Advanced Research,* 06(04), pp. 3419-3424.
DOI: http://dx.doi.org/10.24327/ijcar.2017.3424.0285

****