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Unambiguous s-curve shaping for multipath mitigation for MBOC modulated signals in GNSS

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ABSTRACT

A novel multipath mitigation algorithm for multiplex binary offset carrier (MBOC) signals in the Global Navigation Satellite System (GNSS) is presented. Based on the W2 code correlation reference waveform (CCRW) structure, a series of bipolar reference waveform (BRW) are introduced to shape the unambiguous s-curve. The shaped s-curve has a single stable zero-crossing point, and the problem of unambiguous tracking in MBOC signals is solved. Multipath mitigation capability has also been improved. The proposed method matches the multipath mitigation performance of W2 CCRW. This method can be used in GPS L1 and Galileo E1.

KEYWORDS: Multipath mitigation, MBOC, unambiguous tracking

1. INTRODUCTION

Both the European Galileo system and US GPS will broadcast the new MBOC signal on the L1 band as an interoperable civil signal. The MBOC is defined in the frequency domain and can have different implementations in the time domain [1]. The Galileo system adopts composite binary offset carrier (CBOC) signals. In CBOC signals, the BOC(6,1) and BOC(1,1) components are multiplexed linearly with appropriate amplitude weighting. According to the amplitude of BOC(6,1) component, CBOC could be divided into CBOC+ and CBOC-, with opposite sign of the BOC(6,1) component. The US GPS chooses time multiplex binary offset carrier (TMBOC) signal, with the BOC(1,1) and BOC(6,1) components time-multiplexed. The MBOC signals enjoy the spectral separation from conventional binary phase shift keying (BPSK) modulated signal brought by the BOC modulation. On the other hand, the MBOC signals suffer from the tracking ambiguity caused by the side-peaks in auto-correlation. When the conventional tracking technology, such as narrow correlator (NC) and high resolution correlator (HRC), are applied to MBOC signals, extra zero-crossing points will emerge, which will cause false-lock, leading to biased measurements.

Several methods have been proposed to solve the tracking ambiguity. The “bump-jump” technique proposed in [2] eliminates the threat of falling into false-lock by detecting the energy between the prompt version and the advanced version, but it does not work well in low signal-to-noise ratio (SNR) conditions. Moreover, it will take long time to distinguish the main peak from side-peaks. Since the cross-correlation function (CCF) between MBOC and pure pseudo random noise (PRN) code is similar to the discriminator function of a standard 1-chip spacing early-minus-late (E-L) structure, the BOC-PRN technique utilizes the CCF directly as the discriminator [3]. However, the multipath performance is suboptimal. The method in [4] tracks the subcarrier and the code independently, and could eliminate the tracking ambiguity, but increases the hardware complexity.

In this paper, an ambiguity mitigating technique based on s-curve shaping is proposed. By adding a series of bipolar reference waveforms (BRWs), the new technique can shape the unambiguous s-curve with a single stable zero-crossing point, and can eliminate all the threat of false-lock points and enhance the multipath resistance capacity. The remainder of the paper is organized as follows: Section 2 introduces W2 CCRW technique. Receiver architecture of proposed method is shown in Section 3. In Section 4, the multipath performance of proposed method is analysed. Finally, conclusions are drawn in Section 5.

2. W2 CCRW

W2 CCRW technique is based on the concept of strobe pulse, which was introduced in [5].In those receivers, the incoming signal is correlated with the locally generated gating signal, instead of the early and late version of replica codes. The gating signal is constituted by special tailored element strobe pulses. The element strobe pulse is bipolar symmetrical with level of +1 and -1, and occurs on the edge of each chip, as illustrated in Figure 1, where T_C is the delay of 1 chip, and $g_{W2}(t)$ is the element strobe pulse with the gate width of GW_{W2}.

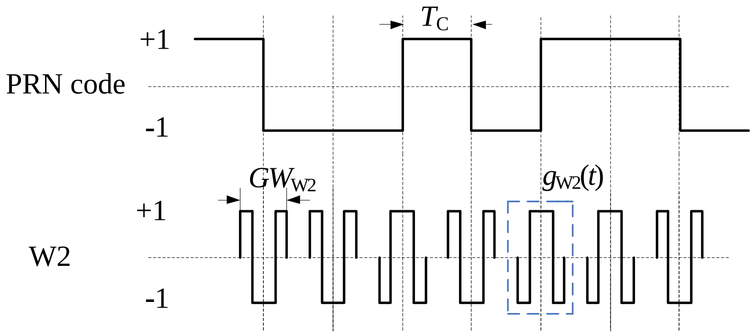


Figure 1. Example of locally generated PRN code and corresponding W2 waveforms.

When applied to MBOC, strobe pulses also occur on the edge of each chip. The subcarriers of MBOC bring new challenges. Firstly, there is a bias on the zero-crossing of s-curve. However, this bias is a systematic error that can be easily corrected. Secondly, the subcarriers introduce extra zero-crossing point in the discriminator output. As shown in Figure 2, in 0.5-chip delay position, there is an extra zero-crossing point. Since the sign of slope of s-curve around ε =0.5

chip is the same as the correct tracking point in ε =0, the extra zero-crossing point is stable and will cause tracking ambiguity. It may lead to biased measurements when the loop remains in the false-locked state, and ambiguous mitigation mechanism is necessary, such as the "bump-jump" technology [2].

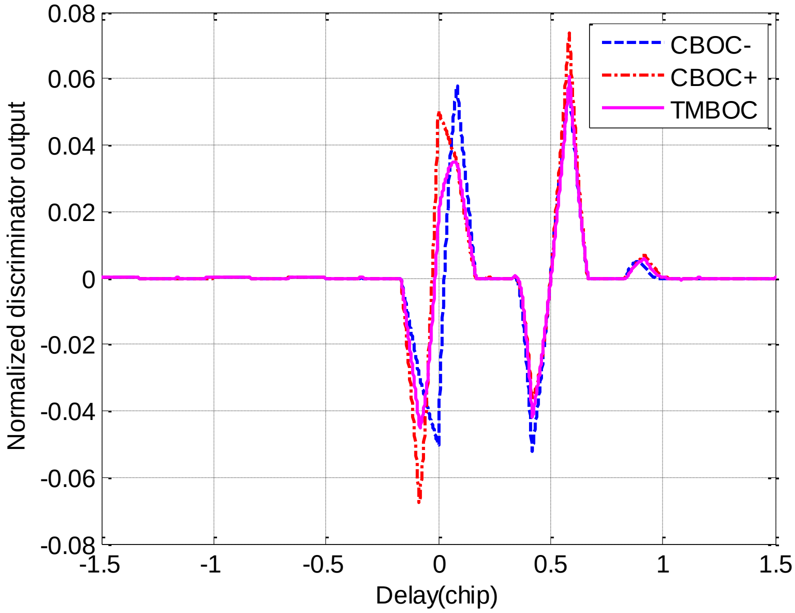


Figure 2. Normalized discriminator output of W2 in CBOC and TMBOC (GW_{W2}=1/3 chip, infinite bandwidth).

3. Proposed s-curve shaping method

To solve the tracking ambiguity of W2 CCRW in MBOC, an additional series of strobe pulses named BRW is introduced in the code tracking loop of the receiver. The BRW was first proposed in [6] and is also constituted by specially tailored strobe pulses, as shown in Figure 3. The BRW is different from W2 since the proposed element strobe pulse is generated when there is a level transition between the previous and the current chip, while W2 belongs to the "per-chip" category. The BRW can be mathematically described as:

$$BRW(t) = \sum_{k=0}^{\infty} g_{\text{BRW}}\left(t - kT_{\text{C}} + \frac{1}{2}T_{\text{C}}\right) c_k(t) \tag{9}$$

where $g_{\text{BRW}}(t)$ is the element strobe pulse, and $c_k(t)$ is the k_{th} ranging chip on the edge of bit transitions.

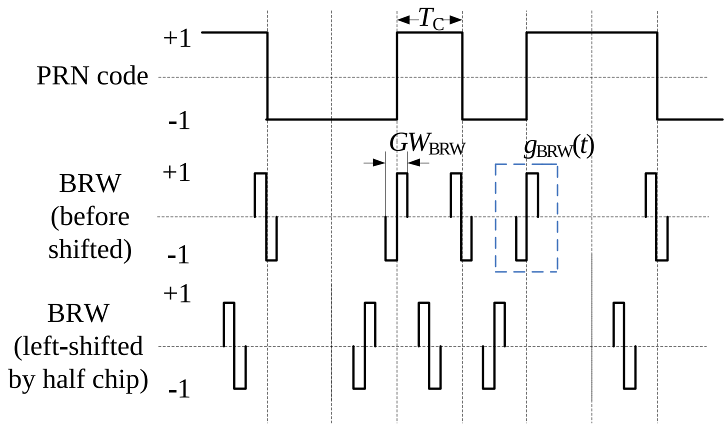


Figure 3. Example of locally generated PRN code and corresponding BRW.

The BRW is generated in two steps. First, the elements of BRW occur on the edge of bit transitions. Second, the BRW is left-shifted by 0.5 chips and final BRW is formed.

The receiver's architecture of proposed method is sketched in Fig. 4. The replica signal and W2 strobes and BRW strobes are generated by the code phase gained by the code discriminator, and are correlated with z_i and z_q, which represent the in-phase and quadrature-phase elements of the incoming signal. The replica signal can be either MBOC signal or BOC(1,1) signal. I_{XX} and Q_{XX} are the correlation of replica signal with z_i and z_q. I_{XW} and Q_{XW} are the correlation of W2 strobes with z_i and z_q. I_{XB} and Q_{XB} are the correlation of BRW strobes with z_i and z_q. The discriminator can be expressed mathematically by:

$$d(\varepsilon)= I_{XW}(\varepsilon)\, I_{XB}(\varepsilon)+ Q_{XW}(\varepsilon)\, Q_{XB}(\varepsilon) \quad (9)$$

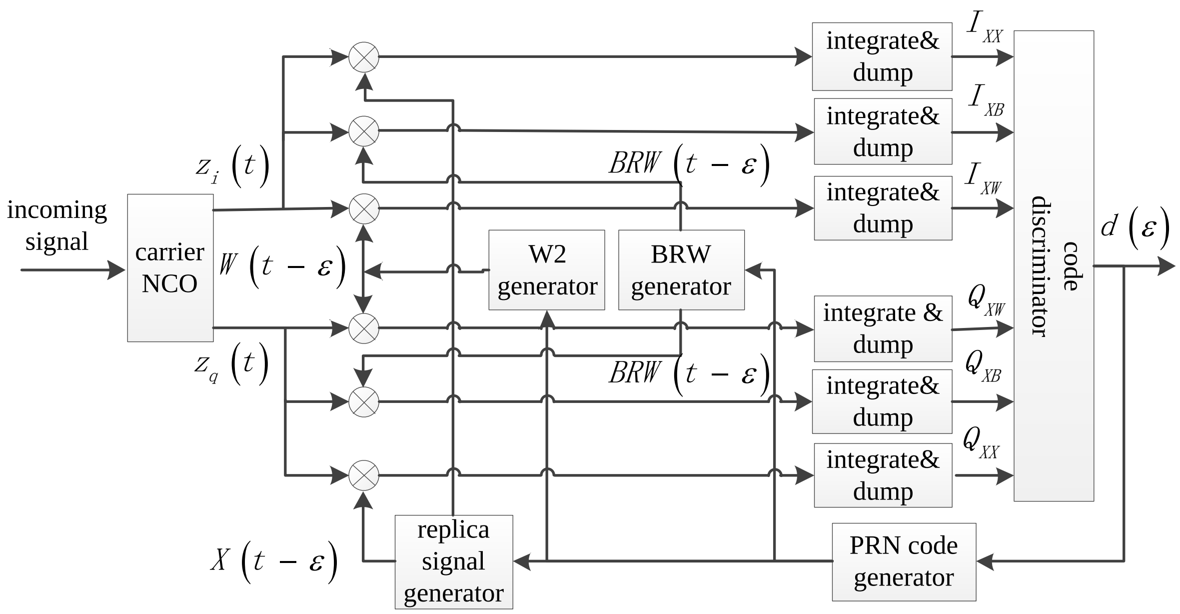


Figure 4. Block diagram of receiver code loop of proposed scheme.

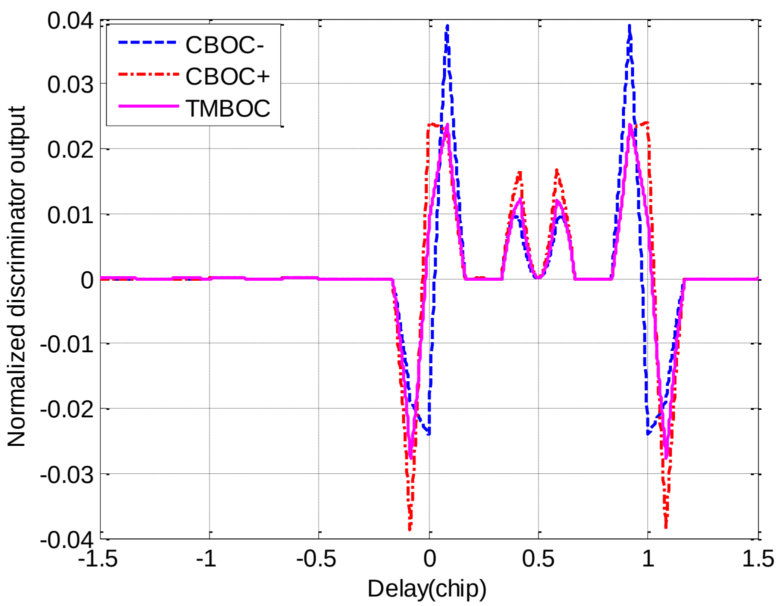
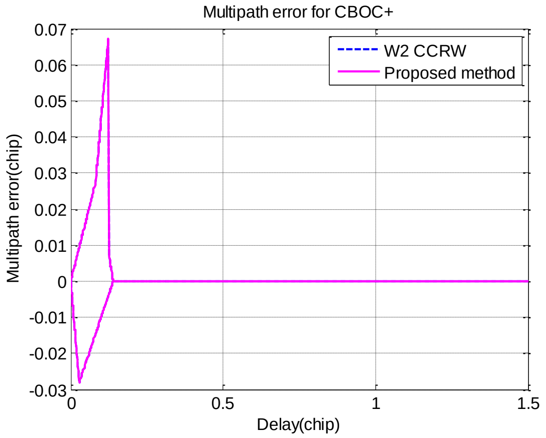


Figure 5. Normalized discriminator output of proposed method in CBOC and TMBOC (GW_{W2}=1/3 chip, GW_{BRW}=1 chip, infinite bandwidth).

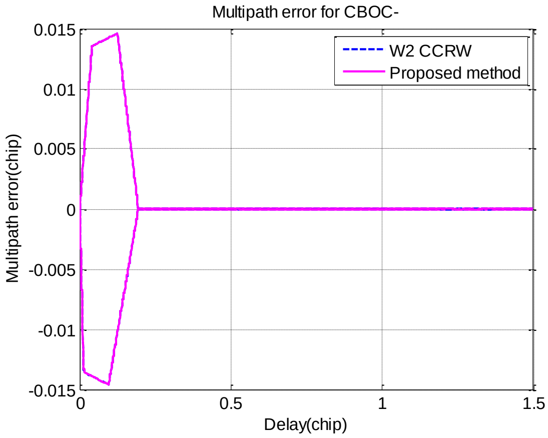
where $I_{XW}(\varepsilon)$ and $Q_{XW}(\varepsilon)$ are the correlation of W2 strobes with z_i and z_q. $I_{XB}(\varepsilon)$ and $Q_{XB}(\varepsilon)$ are the correlation of BRW strobes with z_i and z_q. The shaped discriminator is shown in Figure 5. There still exists a bias on the zero-crossing of s-curve, which could be easily corrected. As to the tracking ambiguity, although there is an extra zero-crossing point in 1-chip delay position, it belongs to unstable node. The slope of discriminator output around in 1-chip delay position is opposite with that of correct lock point, and it could not bring the risk of false-lock. The tracking ambiguity is solved by the unambiguous s-curve shaped by the proposed method.

4. Multipath performance

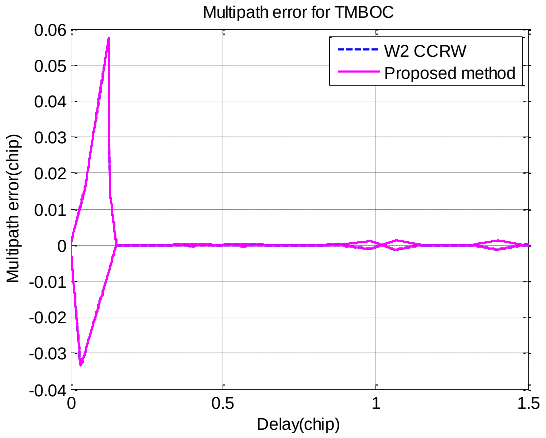
Simulation results are shown to compare the multipath mitigation performances of the proposed algorithm with W2 CCRW for CBOC and TMBOC signals. Assume that the received signal consists of a direct ray and a replica with amplitude of 0.5. Simulation results are plotted in Figure 6. It is shown that the proposed method has same multipath performance with W2 CCRW, and can efficiently eliminate the medium-delay and long-delay multipath.



(a)Multipath error comparison for CBOC+



(b)Multipath error comparison for CBOC-



(c)Multipath error comparison for TMBOC

Figure 6. Multipath error comparison between W2 CCRW and proposed method in CBOC and TMBOC (GW_{W2}=1/3 chip, GW_{BRW}=1 chip, infinite bandwidth).

5. CONCLUSIONS

A multipath mitigation scheme for MBOC signals is presented. Together with W2 waveform and a series of 0.5 chip left-shifted BRW waveforms, an unambiguous s-curve is shaped, and extra false-lock points in the discriminator are eliminated.

The performance of the proposed method for MBOC signals, in the presence of multipath, is compared with those achieved by W2. The proposed solution exhibits identical multipath performance to W2. It only suffers from the short-delay multipath signals. The structure under study is intended as a replacement for the conventional multipath mitigation solutions in GPS and Galileo systems.

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