Implementation of PMF and FFT Acquisition Design for B1C Signal Based on ASPeCT

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Abstract. According to the characteristics of BDS B1C signal, there are many sub peaks in the autocorrelation characteristics, which leads to the ambiguity of B1C signal acquisition. In this paper, the characteristics of B1C signal, acquisition strategy and the ambiguity of different acquisition strategies are analyzed. Based on ASPeCT algorithm, PMF and FFT is implemented in FPGA of navigation receiver. The B1C signal is generated by spiren gss9000 satellite signal simulator, and a test scenario is built for the navigation receiver, which proves the effectiveness of B1C signal acquisition.

Key Words: BDS; B1C; capture; sub peak; ASPeCT; PMF and FFT

1. Introduction
BDS-B1C satellite signal is a new generation of civil signal broadcast only on the Inclined GeoSynchronous Orbit (IGSO) and Medium Earth Orbit (MEO) satellites of BeiDou Navigation Satellite System (BDS-3). In order to effectively utilize the limited navigation band resources, solve the problem of navigation frequency aliasing interference [1] and prevent the loss of signal, the central frequency of B1C is set 1575.42MHz, which overlaps with L1 signal broadcast by the Global Positioning System (GPS). It adopts the modulation mode of binary offset carrier (BOC) and quadrature multiplexed BOC (QMBOC)[2]. Therefore, there are many sub peaks in the auto-correlation properties of B1C navigation signal, which brings ambiguity to the acquisition of B1C signal. According to the characteristics of B1C signal, this paper analyzes the characteristics of B1C signal and the fast acquisition method. Based on the ASPeCT algorithm, PMF + FFT is used in FPGA of navigation receiver terminal. A test environment is set up to verify the effectiveness of this method.

2. Characteristics of BDS-B1C Signal

2.1. B1C Signal Modulation
B1C signal adopts the same center frequency as GPS L1. In order to avoid the conflict between ranging and data transmission performance of navigation signal, B1C signal adopts dual channel signal structure of data component and pilot component. Where, the data component adopts BOC (1,1) modulation mode with navigation message data. The pilot component is the QMBOC (6,1,4/33). It is composed of a BOC (1,1) subcarrier and a BOC (6,1) subcarrier, which are in phase quadrature with each other. The pilot component has no navigation message data. The complex envelope of the B1C signal is expressed as [3]...
The data component of B1C signal is generated by navigation message data and ranging code modulated with the subcarrier, the pilot component is generated by ranging code modulated with the subcarrier. The power ratio of the two components is 1:3. The power ratio of BOC (1,1) and BOC (6,1) with orthogonal pilot components is 29:4, The expression of \( S_{\text{B1C}}(t) \) is defined as follows [4]:

\[
S_{\text{B1C}}(t) = \frac{1}{2} D(t) C_{\text{data}}(t) \text{sign}(2\pi f_{sc\_a} t) + \sqrt{\frac{1}{11}} C_{\text{pilot}} \text{sign}(2\pi f_{sc\_b} t) \\
+ j \sqrt{\frac{29}{44}} C_{\text{pilot}} \text{sign}(2\pi f_{sc\_a} t)
\]  

Where, \( D(t) \) is the navigation message data; \( C_{\text{data}}(t) \) and \( C_{\text{pilot}}(t) \) are the ranging code sequences of the data component and the pilot component respectively. \( \text{sign}(2\pi f_{sc\_a} t) \) and \( \text{sign}(2\pi f_{sc\_b} t) \) are subcarrier. \( f_{sc\_a} \) is 1.023MHz, \( f_{sc\_b} \) is 6.138MHz[5].

2.2. Power spectrum and autocorrelation of B1C

B1C signal adopts dual channel signal structure of data component and pilot component. According to B1C signal expression, its power spectrum is obtained, as shown in 1.

From the power spectrum characteristics of B1C, it can be seen that the difference between the BPSK modulation mode and the original BeiDou Navigation Satellite System is that the subcarrier modulated on the ranging code of B1C signal can divide the single main peak spectrum of BPSK modulation mode into two main peak spectra at the left-right offset of the original BPSK center frequency = 1.023MHz, realizing the main lobe separation. Because the carrier frequency of B1C signal is 1575.42MHz same as that of GPS L1, BOC modulation can effectively solve the problem of spectrum aliasing with GPS L1.

According to the modulation characteristics of B1C signal, the autocorrelation characteristics of BOC (1,1) and QMBOC (6,1,4/33) are obtained by analyzing the autocorrelation of data and pilot components by local reproduction, as shown in Fig.2.
According to the autocorrelation results of B1C signal in the figure above, it can be seen that there is a sub peak at the position of ± 0.5 chips, that is, the correlation accumulation will also have a larger value here. Therefore, when using the traditional BPSK acquisition method, it is easy to judge the sub peak as the "main peak" and capture the wrong chip position [6]. However, the QMBOC (6,1,4/33) modulation of B1C signal can narrow the main peak of autocorrelation and improve the signal receiving accuracy.

3. Strategy of B1C signal acquisition

3.1. Direct matching correlation method

The direct matching correlation method does not consider the influence of subcarrier modulation on acquisition ambiguity in the process of satellite signal acquisition, and adopts the design method of code sliding and FFT to capture the satellite signal directly. The algorithm chart of direct matching is shown in Fig.3.

Fig.3 Block Diagram of Direct Matching Correlation Method

The direct matching correlation method is used for simulation, and the results are shown in Fig.4. It can be seen from the acquisition result graph that due to the characteristics of BOC, there is a main peak and two sub peaks after matching correlation. In weak signal environment, the appearance of sub peak will lead to signal false acquisition.
3.2. ASPeCT method

ASPeCT method can eliminate the sub peak to the greatest extent and keep the main peak unchanged [6]. This method is proposed for BOC (n, n) signals. The principle of this method is that the BOC signal obtained by local reproduction of PN code signal and subcarrier modulation is calculated with satellite signal. The algorithm can be expressed as follows:

\[ R_{ASPect}(\varepsilon) = R^2_{BOC}(\varepsilon) - \beta R^2_{BOC/PN}(\varepsilon) \] (3)

Where, \( R_{BOC}(\varepsilon) \) is the autocorrelation function of BOC signals. \( R_{BOC/PN}(\varepsilon) \) is the cross correlation function between BOC Signal and PN code. \( \varepsilon \) is chip delay. \( \beta \) is the correction coefficient, which can be adjusted to achieve different side peak suppression effect. The autocorrelation function of BOC Signal and the cross correlation function of PN code can be expressed as:

\[ R^2_{BOC}(\varepsilon) = \frac{1}{2} tri_1(\frac{\varepsilon}{l}) - \frac{1}{2} tri_1(\frac{\varepsilon}{2l}) \] (4)

\[ R^2_{BOC/PN}(\varepsilon) = \frac{1}{2} tri_1(\frac{\varepsilon}{l}) - \frac{1}{2} tri_1(\frac{\varepsilon}{2l}) \] (5)

Let \( \beta = 1 \), and equation (3) can be expressed as:

\[ R_{ASPect}(\varepsilon) = tri_0(\frac{\varepsilon}{l}) + tri_0(\frac{\varepsilon}{2l}) \ast tri_1(\frac{\varepsilon}{l}) + tri_0(\frac{\varepsilon}{2l}) \ast tri_1(\frac{\varepsilon}{2l}) \] (6)

\( tri_\alpha(\frac{\varepsilon}{l}) \) is the normalized trigonometric wave function with width \( l \) centered on \( \alpha \). According to the above analysis, the simulation results of BOC signal autocorrelation and PN code cross-correlation function, and the simulation results are shown in Fig.5.

![Figure 4](image1.png)

**Fig.4** Result of Direct matching correlation capture

![Figure 5](image2.png)

**Fig.5** Characteristics of ASPeCT algorithm (\( \beta = 1 \))
It can be seen from the above figure that when the peak value of BOC signal autocorrelation and cross-correlation with local PN code is shifted by ± 0.5 chips, there is a large sub peak. After reconstruction, the autocorrelation function peak size and the corresponding code phase of ASPeCT algorithm do not change, and the width of the main peak is narrowed, the energy of the sub peak is significantly reduced, which can effectively suppress the sub peak.

4. Implementation of Acquisition of BIC

In order to verify the effectiveness of ASPeCT algorithm in B1C signal acquisition, Matlab tool is used to simulate B1C signal, and the combination of ASPeCT method and PMF + FFT is used to realize B1C signal acquisition. Through simulation, it can be seen from Fig.6 that the correlation peak value can be clearly identified by aspect, and B1C signal acquisition can be realized.

![Fig.6 Acquisition results of B1C signal by ASPeCT method](image)

In order to realize the B1C signal acquisition method in engineering, this paper uses FPGA + DSP to design navigation receiver, and the B1C signal acquisition is designed based on ASPeCT method. FPGA mainly completes the demodulation, de expansion, matching correlation operation, chip sliding and spectrum analysis of B1C signal, and finds the carrier Doppler value and code phase corresponding to the maximum correlation accumulation value. The result of Doppler and code phase are put into the "Tong" detector of DSP to judge the threshold and realize the acquisition design of B1C signal.

In order to realize the fast acquisition of B1C signal by navigation receiver and the acquisition ability in high dynamic environment, this paper uses PMF and FFT method to capture B1C signal based on ASPeCT algorithm. Because of the parallel operation characteristic of FPGA, when this algorithm is implemented in FPGA engineering, the parallel 56 channel code and B1C related accumulation operation are adopted, and the pipeline architecture is adopted to complete the work of each module, so as to further improve the acquisition efficiency of B1C. The engineering implementation block diagram of B1C signal acquisition is shown in Fig.7.
1. Digital Down Converter-DDC: The RF chip converts the B1C RF signal to the IF analog signal, and converts it into the IF digital signal through A/D chip. It is mixed with the same phase and orthogonal signal generated by the local carrier NCO to realize carrier stripping, generating I and Q branch digital signals, and completing the down conversion processing.

2. Local PN code generation module(Code_gen): This module can generate 56 channels of local PN code signals, each adjacent two channel chip delay half a chip. Each channel of local PN code signals modulates the subcarriers respectively to generate 56 channels of PN code signals containing subcarriers.

3. Partial matched filtering module(PMF): After stripping the carrier, the I and Q signals are matched and correlated with the 56 channel PN chips generated by the local PN code generator to obtain $corr\_I_{BOC-BPSK\_1...56}$ and $corr\_Q_{BOC-BPSK\_1...56}$. At the same time, every 80 points of the I and Q branch signals after carrier stripping are correlated and accumulated with the local PN code with subcarriers, and the result is obtained $corr\_I_{BOC-BOC\_1...56}$ and $corr\_Q_{BOC-BOC\_1...56}$. In the pipeline timing controller, sliding the local PN chip, the input I and Q signals are correlated and accumulated once every 80 points to realize the partial matched filter operation. 128 correlation and accumulated values are obtained in one B1C code cycle of each I and Q branch. Repeat the above process, and realize all traversal of 10230 chip phases of B1C signal by local PN code sliding.

4. RAM cache module(RAM_stor): After 56 groups of $corr\_I_{BOC-BPSK\_1...56}$ and $corr\_Q_{BOC-BPSK\_1...56}$ are packed, they are sent to 14 dual port SRAM in time sharing, and the dual port RAM output $\{corr\_I_{BOC-BPSK}, corr\_Q_{BOC-BPSK}\}$ is controlled by ram selection controller. The $\{corr\_I_{BOC-BPSK}, corr\_Q_{BOC-BPSK}\}$ value is input to the FFT processing module. In the same operation, after $corr\_I_{BOC-BOC\_1...56}$ and $corr\_Q_{BOC-BOC\_1...56}$ are packed, they are sent to another 14 dual port SRAM in time sharing, and the output $\{corr\_I_{BOC-BOC}, corr\_Q_{BOC-BOC}\}$ is sent to another FFT processing module through the ram selection controller.

5. FFT module(FFT): The 128 accumulated value points of I and Q branches controlled by RAM controller are supplemented with 0 to 256 points, FFT calculation is performed, Doppler spectrum analysis is completed, and the FFT result is modulo calculated, and output $corr\_I^2_{BOC-BPSK}$, $corr\_Q^2_{BOC-BPSK}$, $corr\_I^2_{BOC-BOC}$, $corr\_Q^2_{BOC-BOC}$. In order to
improve the Signal-Noise Ratio of the signal, \( (corr \times I_{BOC-BOC}^2 + corr \times Q_{BOC-BOC}^2)^{1/2} - (corr \times I_{BOC-BPSK}^2 + corr \times Q_{BOC-BPSK}^2)^{1/2} \) is obtained by adder with ASPeCT algorithm and sent to the non-coherent integration module for four times of non-coherent integration, and then sent to the peak comparison module for peak detection.

6. Maximum comparison module (MaxValu_comp): After FFT, the non-coherent integration datas are compared with the maximum accumulated values of each frequency bin, and the frequency bin corresponding to the maximum value is stored. Under the pipeline timing controller, the PN code generator slides the code phases to traverse all the code phases in the B1C cycle. Repeat the previous operation to get the frequency bin ‘max_bin’ and code phase ‘max_chip’, corresponding to the maximum peak value, and send the two results to the "Tong" detector of DSP to realize the fast acquisition of B1C.

5. Acquisition Strategy Validation
The purpose of this paper is to verify the effectiveness of the acquisition of B1C signal in the navigation receiver based on FPGA and DSP architecture using ASPeCT algorithm. FPGA simulation is used to verify the effectiveness of the design. FPGA loads the B1C signal generated by simulation. Through simulation analysis, ‘Max_corr_value’ is obviously higher than other noise signals, as shown in Fig.8. Therefore, the effectiveness of this acquisition design can be proved.

In addition, by building a dynamic test scenario, the B1C signal is captured and verified. The test scenario is shown in Fig.9. In order to simulate the BDS B1C satellite signal, this test uses the B1C RF signal generated by the B1C signal simulator. The acquisition status of B1C signal can be monitored by the software developed by our company.
Tab.1 Main test equipment and parameter setting

| NO. | Equipment / parameter name     | Parameter                  |
|-----|--------------------------------|----------------------------|
| 1   | Test Equipment                | Navigation Receiver        |
| 2   | FPGA                          | XC4VSX55-12ff1148          |
| 3   | Satellite Signal Simulator   | Spiren GSS9000             |
| 4   | Signal frequency              | B1C                       |
| 5   | B1C signal power              | -121dBm                   |
| 6   | BDS SVN                       | 7, 8, 9, 12, 30, 31        |
| 7   | Monitoring software           | HYC UI software            |

After setting up the test scenario according to Fig.9, set the satellite signal simulator to broadcast B1C signal, and set the BDS SvNo according to Tab.1. Adjust the output power of the satellite signal simulator to the navigation receiver, the power is -121dBm, the navigation receiver is powered on, observe the ‘HYC UI’ software, and monitor the acquisition status of B1C.

By observing the ‘HYC UI’ software, it can be seen that the BDS B1C SvNo of 30, 12, 31, 7, 8 and 9 is in the acquisition completion state, and the SNR is about 16dB. In addition, the tracking state ‘CCBF’ of 31 indicates that the frame has been synchronized, and the pseudo range, carrier phase and Doppler information have all been solved, which proves the effectiveness of the acquisition design in this paper.

6. Conclusion
In this paper, according to the characteristics of B1C, the correlation of B1C signal is analyzed, and it is analyzed that using ASPeCT algorithm can effectively weaken the side lobe signal peak of B1C signal autocorrelation characteristics, while the main peak value remains unchanged, and the main peak width is narrower, and the corresponding chip position does not change. Based on this algorithm, it is implemented by PMF and FFT in FPGA project. In addition, by building a test scenario and observing the receiving state of B1C signal, the effectiveness of B1C signal acquisition design is effectively proved.

References
[1] Chris Hegarty, Betz John-W, Saidi Ali. Binary coded symbol modulation for GNSS[A], 2001: 56-64.
[2] Yao Zheng, Lu Mingquan, Feng Zhenming. QMBOC modulation and its multiplexing techniques[J]. SCIENTIA SINICA Phys, Mech & Astron, 2010,40(5): 575-580.
[3] Latour A D, Grelier T, Artaud G, et al. Subcarrier Tracking Performances of BOC, ALTBOC and MBOC Signals[J]. Proceedings of International Technical Meeting of the Satellite Division of the Institute of Navigation, 2007:769-781.
[4] Feng Rui, Ma Hong, Ren Yufei. B1C Singal Modulation Implementation and Performance Analysis [J]. Radio Engineering, 2019, 49(2) : 95-100.
[5] BeiDou Navigation Satellite System Signal In Space Interface Control Document- Open Service Signal B1C (Version 1.0). China Satellite Navigation Office, 2017.
[6] Ye Lvyang. Simulation Generate and Performance Analyse on BDS-3 B1C Singal[D]. Beijing: University of Chinese Academy of Sciences, 2019
[7] Feng Rui, Ma Hong, Ren Yufei. Non-matching acquisition research of B1C signal[J]. Electronic Measurement Technology, 2019, 42( 1) : 132-137.