Research on BOC Signal Characteristics and Code Acquisition Methods

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***Abstract*—The new generation of navigating and positioning system which used a more effective BOC modulation, has more advantages such as smaller crosstalk with BPSK, anti-fading ability etc. This paper describes the principle, performance of binary offset carrier (BOC) modulation, and the characteristics of spread spectrum signal; it analyzes the highly efficient method of acquisition and code tracking, which provides a new train of thought for enhancing signal acquisition speed, effectively reducing the probability of the wrong lock and saving hardware cost.**

Keywords-BOC; acquisition; simulation

I. INTRODUCTION

With the construction of new generation navigation system—the European Galileo satellite navigation system and the progress of GPS modernization in United States, a new type of satellite navigation signal structure has become the focus of attention.[1] [7] The introduction of BOC modulation becomes the main choice of the new GPS-M code and the Galileo navigation system, which can reduce signal interference between each other to improve the positioning performance, it meets the new needs of the navigation development, implements the spectrum splitting and takes full advantage of the existing spectrum resources, and has a better performance than traditional BPSK modulation , so that we can improve the accuracy of location according to the related characteristics. This paper introduces the structure, spectrum, power spectrum and correlation function characteristics of BOC modulation. Referring to the multi-peak structure of the BOC modulation signal related function, which easily makes the fuzzy capture, it analyzes different signal processing methods and provides the reference for the design of the navigation receiver.

II. BOC SIGNAL STRUCTURE

Binary Offset Carrier (BOC) modulates the satellite signal with a square wave as a sub-carrier, and then modulates to the main carrier, namely the signal s(t) and a frequency of f_s sub-carrier multiplied, making the signal spectrum split into two parts, located in the left and right of main carrier frequency. BOC modulation is a creative service of satellite navigation system, and its main characteristics of signal structure is that the signal power is not located in main lobe of the carrier spectral, but in side-lobe, which 2 times the subcarrier bandwidth. [2] In fact, BOC signal is an extension of BPSK modulation; the latter just has no subcarriers. BOC signal uses the simplest form of spread spectrum sequence; all the subcarriers and spreading codes use binary format. In the future, spreading sequences with extended alphabets [ternary,5-ary,..] might be used. Assumptions $2T_s$ (corresponding to f_s) is a sub-carrier of the cycle, pseudo-random code (PRN) for the cycle T_c (corresponding to f_c), Spreading codes subject to independent and identical distribution, while k expresses the number of subcarriers, when the spreading codes remain unchanged, thereby

$$f_s = \frac{1}{2T_s},\ f_c = \frac{1}{T_c} = \frac{1}{kT_s},\ \frac{f_s}{f_c} = \frac{k}{2} \tag{1}$$

GNSS satellites have a frequency of atomic clock as a reference f_0 BOC signal carrier frequency, sub-carrier frequency f_s, code rate f_c are all chosen as the integer multiple of f_0, which may have

$$f_s = m \cdot f_0, \qquad f_c = n \cdot f_0 \tag{2}$$

Thus, BOC signal can be expressed as $BOC(m,n)$,in order to simplify, often *m*, *n* have taken the integer. If we make $f_0 = 1.023$ MHz, then $BOC(m,n)$ expresses the spreading codes rate chooses $n \cdot f_0 = n \cdot 1.023$ MHz, sub-carrier frequency is $m \cdot f_0 = m \cdot 1.023$ MHz. BPSK signal complex envelope can be expressed by the following formula

$$s_{BPSK}(t) = \exp(-i\theta)\sum_j a_j \cdot \mu T_c(t - jT_c - t_0) \tag{3}$$

Where a_j is a modulated signal, $\mu T_c(t)$ is spread-spectrum code, θ and t_0 are the carrier phase and code delay. Thus, the complex envelope of BOC signal can be expressed as follows

$$\begin{aligned} s(t) = \exp(-i\theta)\sum_j a_j \cdot \mu_{kT_s}(t - jkT_s - t_0) \\ \cdot cT_s(t - t_0) \end{aligned} \tag{4}$$

Where $c_{T_s}(t)$ is a sub-carrier cycle, μ_{kT_s} is the cycle of spread-spectrum and k is the number of subcarriers.

When k is an even, $BOC(f_s, f_c)$ signal spectrum can be expressed as[3],

$$G(f)=\frac{1}{kT_s}\left(\frac{\sin(\pi fT_s)\sin(k\pi fT_s)}{\pi f\cos(k\pi fT_s)}\right)$$
$$= f_c\left(\frac{\tan\left(\frac{\pi f}{2f_s}\right)\sin\left(\frac{\pi f}{f_c}\right)}{\pi f}\right)^2 \quad (5)$$

When k is odd,

$$G(f)=\frac{1}{kT_s}\left(\frac{\sin(\pi fT_s)\cos(k\pi fT_s)}{\pi f\cos(k\pi fT_s)}\right)$$
$$= f_c\left(\frac{\tan\left(\frac{\pi f}{2f_s}\right)\cos\left(\frac{\pi f}{f_c}\right)}{\pi f}\right)^2 \quad (6)$$

III. THE ANALYSIS OF BOC SIGNAL SPECTRUM AND RELATED CHARACTERISTICS

The spread spectrum signal is modulated by BOC (BOC2DSSS), whose base-band auto-correlation function has the multi-peak characteristics, and the peak depends on the ratio of the sub-carrier and the spread-spectrum code rate. Signal power spectrum and auto-correlation characteristics are mainly decided by the two parameters, f_s and f_c , the correlation can be expressed as,

$$n_1 = \frac{2f_s}{f_c} \quad (7)$$

Where n_1 expresses the number of main lobe and side-lobe between the two main valve, f_s is sub-carrier frequency, f_c is the bit rate. From this we can calculate the number of main valve and side-lobe is 2 (that is, there is no side-lobes between the two main valve) for the BOC(5,5), the number of main valve and side-lobe is 4(namely there are 2 side-lobes between the two mainvalve) for BOC(8,4). At the same time, this two BOC modulation parameters determine the auto-correlation function peak and negative peak, corresponding to their specific relationship as follows:

$$n_2 = \frac{4f_s}{f_c} - 1 \quad (8)$$

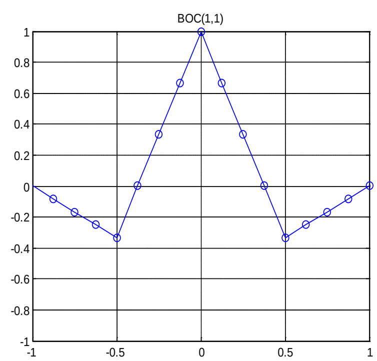
Where n_2 is the number of the auto-correlation function peak and negative peak, while the delay time of the two adjacent peaks equals to the half cycle of the sub-carrier (namely square wave). From this we can calculate the BOC (5 ,5) ,the number of positive and negative peaks is 3, the delay time of the adjacent peaks is 97ns; BOC(8 ,4) ,the number of positive and negative peaks is 7,the delay time of the adjacent peaks is 61ns.

The frequency characteristics of BOC modulation signal which determine its correlation function will appear a number of peaks. The number of positive and negative peak is 2n-1 (n=2fs/ fc). The interval between these peaks is Ts. For example, BOC (1, 1) , the auto-correlation function of the signal will have one peaks. Figure 1 and Figure 2 is the auto-correlation function for BOC (1,1)and BOC (6,1), in which n=6, so we can forecast its auto-correlation function will have 11 peaks.

Signals spectrum distributes in the upper and lower sideband of both sides of the spectrum. The two enveloped center frequency are separately ±10.23 MHz. We can observe that the BOC DC components of the signal spectrum is zero (energy-free), which can isolate the M code and C / A code well.

With the partition of the multiple peak, the width of the main peak interval reduced, which is helpful to reduce delay between the lead and lag correlator when tracking code in the receiver. At the same time, the Line slope near main peak of gets great, which can increase the phase sensitivity and improve the tracking accuracy.

BOC Signal has a special spectrum due to the modulation of a square wave. Figure 1 and Figure 2 are separately the spectrum of BOC(1,1) and BOC(6, 1).From the two spectrums can be seen that most of the power concentrated on both sides of zero-frequency , and the greater the value, the farther the distance of the main valve from the zero frequency. In this way, modulation signal can be transmitted with the ordinary or modulated code concentrated in the vicinity of zero-frequency, which improves the transmission efficiency greatly.



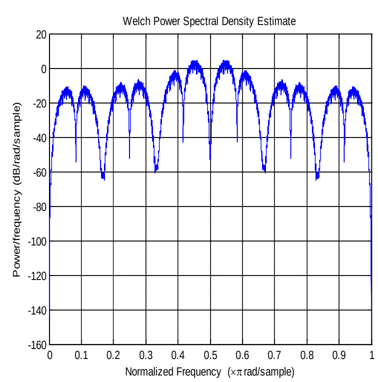


FIGURE I. AUTO-CORRELATION FUNCTION AND POWER SPECTRAL OF BOC(1,1) SIGNAL.

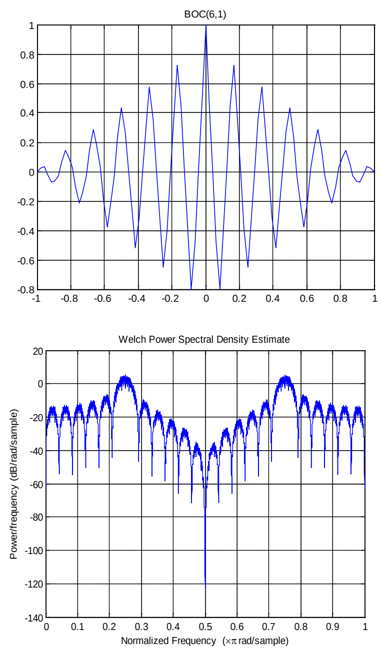


FIGURE II. AUTO-CORRELATION FUNCTION AND POWER SPECTRAL OF BOC(6,1) SIGNAL.

The main lobe of BOC signal is not the center of the horizontal axis of zero-frequency location, but offset to either side of a certain distance, for the sinusoidal sub-carrier, the peak is in the main lobe center locations tend to zero frequency; for cosine sub-carrier, the peak of the main valve center frequency deviation from the zero position. From zero to both sides, there are two main lobe valves, but in a single rectangular pulse pseudo-code there is only one main lobe, which is equivalent to a single rectangular pulse has been pseudo-code sub-carrier modulation, the main lobe divided into two, and this is the so-called "spectrum split".

IV. THE ANALYSIS OF CODE ACQUISITION METHODS IN BOC RECEIVER [4][5][6]

The principle are the same between BOC signal receiver and the *PN* code spread spectrum receiver, They all require code synchronization, carrier synchronization, bit synchronization, as well as pseudo-code and information demodulation, but main difference between them is in the technique of code synchronization. Spread spectrum communication and wireless navigation systems require the receiver to restore the signal and the received signal waveform strictly synchronous; if the time delay between them has a small amount of bias, then the received power will weaken, which leads to unreliable data detection and larger pseudorange measurement error. To achieve code synchronization the receiver generally carried out in two steps: First, code acquisition, namely, the completion of phase detection code, second is to maintain synchronization after capture, which is to be the tracking code.

BOC signal spectrum has two symmetrical bands; the correlation function is a multi-peak structure, so it adds to the complexity of processing way. We know that the ordinary use of DSSS communication only has a *M* sequence to produce *PN* sequences, using the good autocorrelation features of sequence to ensure the code synchronization.

For example: when m = 10, *PN* sequence length is 1023, its auto-correlation function is

$$R_{PN}(\tau) = \begin{cases} 1023, & \tau = 0 \\ -1, & \tau \neq 0 \end{cases} \tag{9}$$

The BOC modulation of the Galileo system is equivalent to the addition of a multiply operation after the spread-spectrum, such as BOC (10, 5)

$$s(t) = c(t)\,pn(t)\,f_s(t) \tag{10}$$

where $f_s(t)$ is +1, -1 interval of square wave, the characteristics of the autocorrelation of $f_s(t)$ is:

$$R_a(t) = \begin{cases} 4, \tau = 0, \pm 2, \pm 4, \cdots \\ -4, \tau = \pm 1, \pm 3, \cdots \end{cases} \tag{11}$$

From the above two, the auto-correlation characteristics of $pn(t)\,f_s(t)$ is multi-peak. The number of peaks and the gap between peaks depends on the BOC modulation factor, that is, the ratio of *m* and *n*. Repeat the above process. Searching process covers the two-dimensional plane formed by entire *PN* code in all carrier phase and the largest Doppler frequency shift, each searching unit composed by a *PN* code phase stepper and a stepper in the Doppler frequency component. E5a signal is approximately with QPSK signal, which carries the information of data path and navigation channels, after the relevant integration of the *PN* code in data channels, it leaves only the data channel auto-correlation characteristics. Because of the inter-related characteristics of *PN* codes, the pilot channel information is filtered out.

Thus, using Matlab software for simulation, the signal passing through-10dB channel, *PN* code phase step is 667Hz, the Doppler shift error calculated during simulation is within [-8KHz, +8 KHz], code phase error is within [-5 , +5], searching for various unit value, so we get related to flat as shown in Figure 3.From it we can see that the searching unit will get the largest related value when the Doppler shift in the error code is 0 and the phase error is 0; the large number reflects the good correlation.

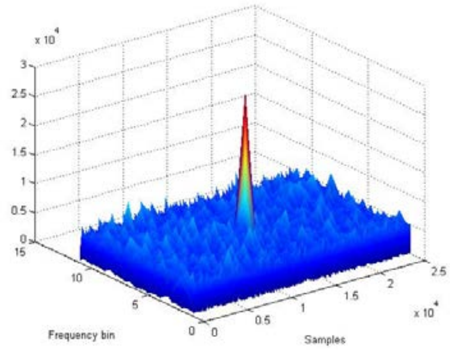


FIGURE III. CORRELATED VALUE OF SEARCHED UNIT.

The spread-spectrum communications receivers for satellites have a very important algorithm, which is the *PN* chip of the capture. Capture time, hardware and software complexity, the probability of false alarm, undetected error are all standards for assessing its quality. Ordinarily, we use two methods to capture spread spectrum code. Matched filter and sliding correlation method are based on a high degree of auto-correlation characteristics. But the difference is that the former chip uses the intermediate frequency signal of different time to match the filter using reverse sequence of the local chip as filter coefficients, while the latter uses the local chip slips in a cycle in order to capture the opportunity. Matched filtering method has high capture speed, but it consumes the hardware resources and the sliding correlation method is simple. Its low hardware resource consumption and extent allowed by the hardware, which makes the multi-chip slide catch paralleled.

V. CONCLUSIONS

Binary-offset-carrier (BOC) signals pose significant challenges for the code acquisition, due to the ambiguities (deep fades) which are present in the envelope of the correlation function (CF). This article has carried on the detailed analysis to the new BOC signal characteristic. Through the analysis of the power spectral density function we know BOC signal has split spectrum. This paper assesses the performance of two methods allowing to acquire and track BOC signal unambiguously.

With the GPS modernization and the promotion of GALILEO system, more and more people are familiar with the new term of BOC. However, the study of BOC is in constantly improving, many scholars have put forward their own research results; we can learn a lot from them.

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