Chip Pulse Design for an Additional Satellite Navigation Signal in L6 Band

Hyoungsoo Lim, Sang Uk Lee, Joon Gyu Ryu
Telecommunications & Media Research Laboratory
Electronics and Telecommunications Research Institute
Daejeon, South Korea
lim@etri.re.kr

***Abstract*—** According to increasing needs for advanced services in satellite navigation system, an exhaustive search method of chip pulse design for an additional service signal is proposed. The candidate waveforms considered include BPSK, BOC, and BOCcos. In this paper, the design is performed for three candidate chip rates of 1.023, 2.046, and 10.23Mcps. The preliminary design results presented in this paper are chosen to minimize the worst interference to the existing legacy satellite navigation system with practical implementation complexity of the satellite signal generator and the corresponding receivers as well.

Keywords—pulse design; satellite navigation system; spectrum separation coefficient

I. Introduction

Recently, the importance of satellite navigation services are greatly increasing, especially in unmanned autonomous land and aerial mobility systems. However, the existing systems have limited capacity and capabilities and thus there have been efforts to modernize the system with enhanced capacity and capabilities.

In this paper, we propose a chip pulse design method and the results for a new service signal in either an existing or a new satellite navigation system. The L6 band is considered since it is the least crowded in the L bands for satellite navigation services. Although, Galileo E6, BDS (BeiDou Navigation Satellite System) B3, and QZSS (Quasi-Zenith Satellite System) LEX (L-band Experiment) signals are already using the L6 band as shown in Table I [1-3]. Therefore, a careful design is needed for the new signal to avoid interference to them.

TABLE I. Legacy Satellite Navigation Signals in L6 Band

System	*Service*	*Chip pulse*	*Center frequency*
Galileo	E6 CS E6 PRS	BPSK(5) BOCcos(10, 5)	1278.75 MHz
BeiDou II	B3-I AS B3-Q AS	BPSK(10) BPSK(10)	1268.52 MHz
BeiDou III	B3I B3-A B3	BPSK(10) BOC(15, 2.5) BPSK(10)	1268.52 MHz
QZSS	LEX	BPSK(5)	1278.75 MHz

II. Design Scope

In this paper, we propose an exhaustive search based chip pulse design. The well-known chip pulse waveforms of BPSK (Binary Phase Shift Keying), BOC (Binary Offset Carrier), and BOCcos (BOC with Cosine Phasing) [4-5] are considered since the three have been widely used in the existing legacy satellite navigation systems and their performance, efficiency, and implementation complexity have been well verified by numerous researches. There can be a new waveform than the three with better characteristics but, unless their performance, efficiency, and implementation complexity differ significantly, adoption of a well-proven waveform can avoid any unexpected risks.

When a chip rate of the new signal is given from its requirements of the data bit rate and transmission performance, the parameters to design are the waveform – BPSK, BOC, or BOCcos – and, in the cases of BOC and BOCcos, the subcarrier frequency offset.

For the sake of implementation complexity, in the existing legacy satellite navigation systems, the subcarrier frequency offsets for BOC and BOCcos have been designed to be multiples of the chip rate. Exceptionally, those for the Alternative BOC AltBOC(15, 10) of Galileo E5 [1], ACE (Asymmetric Constant Envelope)-BOC(15, 10) of BeiDou III B2 [6], and BOC(5, 2) of NavIC (Navigation with Indian Constellation) RS (Restricted Service) [7] are multiples of a half of the chip rate. Thus, in this paper, we extend the scope of the subcarrier frequency offset to all possible multiples of a half of the chip rate.

In this paper, we use the SSC (Spectral Separation Coefficient) [8] to evaluate the interference between the new signal and an existing legacy one. This can greatly reduce the design complexity as the SSC can be considered to be an asymptotic analysis of interference when the spreading codes, timing, and phase of the two signals are random.

III. Design Conditions

As examples in this paper, we consider three chip rates: 1.023 Mcps, 2.046 Mcps, and 10.23 Mcps. The two numbers 1.023 Mcps and 10.23 Mcps are the minimum and the maximum values used in the existing legacy systems.

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The center frequency is 1278.75 MHz and the bandwidth of 40 MHz is assumed available. The main lobe(s) of the signal spectrum shall be within the given frequency band ranging from 1258.75 MHz to 1298.75MHz.

The center frequency can also be designed for optimal performance but it is left for further research and is not considered in this paper.

IV. Design Method

The design procedure proposed in this paper is as follows:

Step 1: Calculate the worst SSCs for all possible combinations of parameters of BPSK(*n*), BOC(*m*, *n*), and BOCcos(*m*, *n*), where *n* denotes the chip rate of 1.023*n* Mcps and *m* denotes the subcarrier frequency offset of 1.023*m* MHz for BOC and BOCcos waveforms. The worst SSC is the maximum SSC observed for a new signal to and from every existing legacy signal. The chip rate factor *n* covers all positive multiples of 0.5 in order to include the BOCcos(15, 2.5) of Galileo E1 PRS (Public Regulated Service). As aforementioned, the subcarrier frequency offset factor *m* covers all multiples of *n*/2 not less than *n* for integer *n* in order to include the BOC(5, 2) of NavIC RS. When *n* is an odd multiple of 0.5, *m* covers positive multiples of *n*.

Step 2: Find the waveform and the parameter(s) which has the minimum worst SSC.

When the interference is a critical issue, the design procedure stops here. Otherwise, if some margin is available in the interference requirement, we can go a trade-off between the interference and the signal bandwidth as follows and lower the implementation complexity:

Step 3: If the minimum worst SSC is obtained with either BOC or BOCcos of a large subcarrier frequency offset and the minimum worst SSC has enough margin against the interference requirement, extend the tolerable range for the SSC and find the waveform with minimum *m* resulting in an SSC within the extended range.

The consideration of narrow bandwidth and low complexity is especially important for OS (Open Service), accommodating low-cost receivers.

V. Results and Analysis

The chip pulse design for minimum worst SSC result obtained in Step 2 of the design procedure in the previous section is shown in Table II. The achievable minimum worst SSCs can be considered low since the values are within the range of SSCs among existing legacy navigation satellite signals, -88.360 to -73.680 dB.

Table II assumes the subcarrier frequency offset can be a multiple of a half the chip rate. If we need to confine it to be a multiple of the chip rate, we have BOC(14, 1) instead of BOCcos(3.5, 1). However, the subcarrier frequency offset is as high as 14.322 MHz and the main lobe of the signal spectrum spans as wide as 30.690 MHz, which is practically unacceptable.

Now, let us tolerate a marginal interference increase for a practically better chip pulse design with narrower signal bandwidth. With the interference increase up to 1 dB tolerated, the narrowest bandwidth we can obtain is BOCcos(3, 1) for 1.023 Mcps which has slightly narrower bandwidth than BOCcos(3.5, 1). For the other chip rates, we have the same chip pulses as those with minimum worst SSCs.

VI. Conclusions

In this paper, a exhaustive search based chip design method and results are presented for a new satellite navigation service in L6 bnad. The chip pulse design was performed for examples of 1.023 Mcps, 2.046 Mcps, and 10.23 Mcps. The chip design was performed to minimize the worst SSC to and from the existing legacy satellite navigation signals and, at the same time, to minimize the signal bandwidth and thus the implementation complexity.

For a given chip rate, the parameters to design is the waveform – BPSK, BOC, or BOCcos – and the subcarrier frequency offset. The resulting chip pulses for 1.023 Mcps are BOCcos(3.5, 1) and BOCcos(3, 1). The former has the lowest SSC of -75.2103 dB but the subcarrier frequency offset is a multiple of a half the chip rate. On the other hand, the latter has the subcarrier offset an integer multiple of the chip rate but has 1.28 dB higher SSC than the former. The pulses for 2.046 Mcps and 10.23 Mcps are respectively BOCcos(6, 2) and BOC(10, 10).

It should be noted that the method and results in this paper is given for the case when the center frequency is fixed to be 1278.75 MHz and a single service signal is additionally transmitted in L6 band. As the BDS signal spectra have -10.23 MHz offset from the center frequency of Galileo and QZSS, 1278.75 MHz, we can consier the center frequency offset as an additional design parameter for any further improvement. Furthermore, if two or more new service signals are to be transmitted, various additional aspects should be considered such as interference among the new additional signals, complexity and bandwidth requirement to meet the target features of each service and the composite signal after multiplexing. Also, the multiplexing should meet the constant envelope requirement for the efficiency of the high power amplifiers in the satellite payloads.

TABLE II. Chip Pulse Design Results for Minimum Worst SSC

Chip rate	*Chip pulse*	*Worst SSC*
1.023 Mcps	BOCcos(3.5, 1)	-75.2103 dB
2.046 Mcps	BOCcos(6, 2)	-74.6195 dB
10.23 Mcps	BOC(10, 10)	-74.6125 dB

TABLE III. Chip Pulse Design Results for Close-to-Minimum Worst SSC with the Subcarrier Frequency Offset ≤ 10.23 MHz

Chip rate	*Chip pulse*	*Worst SSC*
1.023 Mcps	BOCcos(3, 1)	-73.9278 dB
2.046 Mcps	BOCcos(6, 2)	-74.6195 dB
10.23 Mcps	BOC(10, 10)	-74.6125 dB

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