Selective Carrier Frequency Offsets to a Subgroup of Navigation Satellite Signals under Constant Envelope Multiplexing

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***Abstract*—A scheme is proposed for selective application of CFO (Carrier Frequency Offset) to a pair of navigation satellite signals in orthogonal phase relationship at CEM (Constant Envelope Multiplexing.) The proposed scheme has low implementation complexity and can be useful in signal design for a new navigation satellite system using a frequency band where the spectra of the existing legacy signals are asymmetrically distributed in frequency. When the signal pair for CFO are bi-phase signals with equal power, the proposed scheme is especially attractive since the same CEM scheme can be used as that without the selective CFO.**

***Keywords*—carrier frequency offset, constant envelope multiplexing, navigation satellite signals**

I. Introduction

Every legacy navigation satellite system simultaneously transmits several – up to five – signals at an identical carrier frequency per frequency band and their PSDs (Power Spectral Densities) are distributed symmetrically. However, inter-system interference can be asymmetric when the carrier frequency of any system is different from others. Specifically, the carrier frequencies of GLONASS (Global Navigation Satellite System) and BeiDou B3 are different from GPS (Global Positioning System), Galileo, IRNSS (Indian Regional Navigation Satellite System), and QZSS (Quasi-Zenith Satellite System) [1-6]. As a result, in the L6 band for example, we have asymmetric spectrum distribution as shown in Fig. 1.

When we are going to deploy a new navigation satellite system in a frequency band with asymmetric interference distribution, its signals can be designed to have asymmetric spectrum distribution in order to mitigate inter-system interference. One of the straightforward method for asymmetric spectrum distribution is application of CFOs (Carrier Frequency Offsets) to a subgroup of the signals. However, it is not simple since the implementation complexity of the signal generator can be large and it can also be difficult to design the CEM (Constant Envelope Multiplexing) scheme for the signals with selective CFOs.

In this paper, we propose a feasible scheme for selective CFO application to a subgroup of navigation satellite signals at low complexity without the need for efforts to design a new CEM scheme.

II. Proposed Scheme for Selective CFO

One of the most important requirements in designing a new navigation satellite system is that the interference from the new signals with the signals of the existing legacy systems shall be negligible. At the same time, the interference from the legacy signals with the new signals should be sufficiently low. In the case of the L6 band, as we can see from Fig. 1, the frequencies ranging from 1263.405 MHz to 1273.635 MHz can suffer significant interference from both Galileo E6 PRS (Public Regulated Service) and BeiDou B3I/Q signals. If we design signals for a new navigation satellite system in the L6 band, it is desirable to avoid this frequency range.

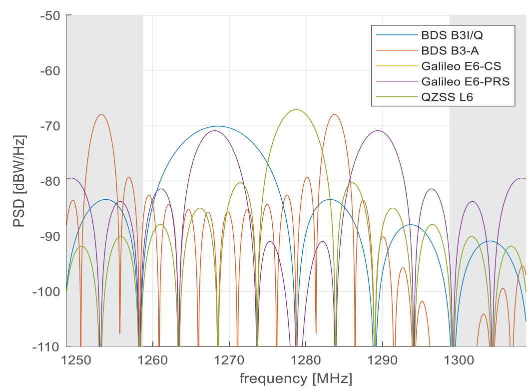


Fig. 1. Spectra of legacy navigation satellite signals in the L6 band.

As mentioned in the introduction, the simplest resolution is to apply carrier frequency offsets to a subgroup of signals as

$$s_{typ}(t) = e^{j2\pi\Delta f t} s_0(t), \tag{1}$$

where Δf denotes the CFO and $s_0(t)$ denotes the original signal without CFO. However, the phase of $s_{typ}(t)$ varies in continuous time and it is impracticable to design a CEM scheme for the signals with selective CFO. Thus, the schemes of the selective CFO and the CEM should be jointly designed. In this paper, on the other hand, we propose a simple scheme that an identical CEM scheme can be used irrespective of application of selective CFO.

Implementation of a CFO becomes simple when the complex tone $e^{j2\pi\Delta f t}$ in (1) varies in discrete time, $t = n/f_s$ and the CFO is $\Delta f = \pm f_s/4$, where f_s is the sample frequency of the selective CFO tone. Similarly to all the legacy navigation satellite signals, the new signal $s_0(t)$ is also assumed to have a sample-and-hold type waveform and f_s is a multiple of the sample frequency of $s_0(t)$. The proposed scheme can be written as

$$s_{new}(t) = \frac{1}{\sqrt{2}}\left(c_I(t) \pm jc_Q(t)\right) s_0(t), \tag{2}$$

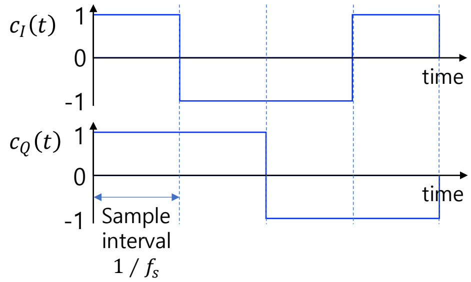


Fig. 2. Waveforms of $c_I(t)$ and $c_Q(t)$ for the proposed selective CFO.

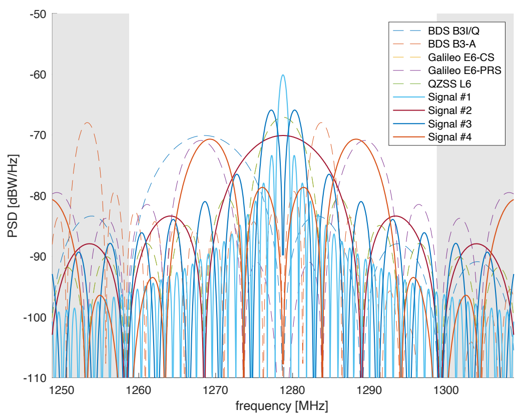


Fig. 3. Spectra of the new signals in the L6 band without selective CFO.

where $c_I(t)$ and $c_Q(t)$ are the bi-phase signals repeating the waveforms in Fig. 2. The proposed scheme can be implemented at low complexity as it only requires simple sign inversion of the original signal, $s_0(t)$. However, similarly to the case of (1), the phase of $s_{new}(t)$ also varies in time and thus, when it is multiplexed with the other signals, the time-varying phase relationship among the signals makes the CEM design significantly difficult or complicated.

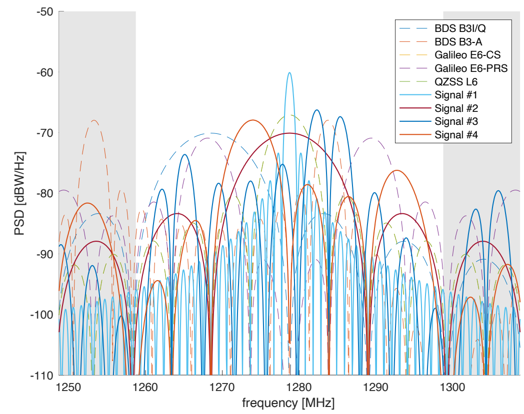
Fortunately, we can avoid the problem if we apply the proposed scheme to a pair of equal-power bi-phase signals in orthogonal phase relationship at CEM. With the proposed selective CFO scheme, the phase orthogonality between the signal pair is maintained and the phase relationship with the other signals only varies by $\pm\pi/2$. Thus, we can use the CEM scheme without any modification. Furthermore, we can apply CFOs with distinct signs, $-f_s/4$ and $f_s/4$ to each signal of the pair without any additional complexity.

III. Examples with Selective CFOs

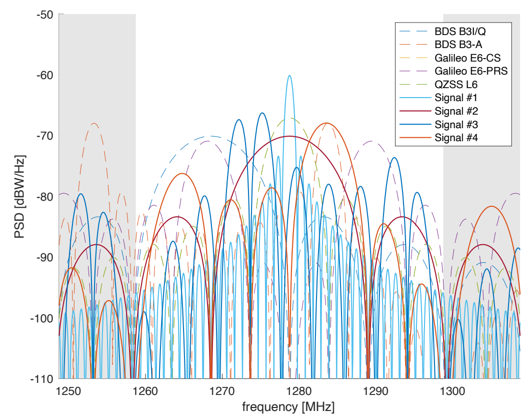
Let us consider, for example, the case where four new signals are additionally transmitted in the L6 band with arbitrary bi-phase modulation schemes of BPSK(1), BPSK(10), BOC(2, 2), and BOC(10, 5). The two BOC (Binary Offset Carrier) signals are assumed to have equal powers and orthogonal phase relationship at CEM.

A. Signals without Selective CFO

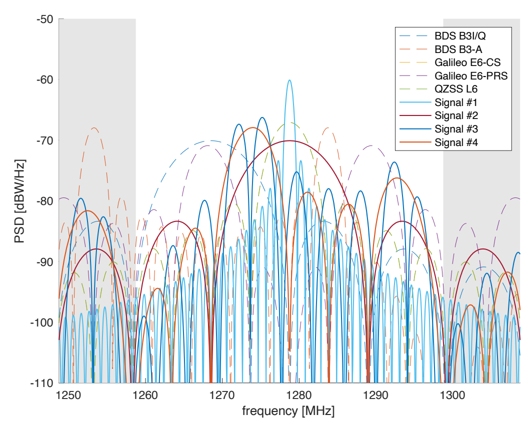
Fig. 3 shows the PSDs of the four new signals without selective CFO. The dashed curves show the PSDs of the legacy signals in Fig. 1 as references. We can see that the PSD of the BOC(10, 5) signal significantly overlaps those of BeiDou B3I/Q and Galileo E6 PRS signals. In this example, it would be desirable to apply the proposed selective CFO scheme to the BOC(10, 5) signal together with its equal-power orthogonal-phased pair, the BOC(2, 2) signal.



(a) CFO of 5.115 MHz for Signals #3-4.



(b) CFO of -5.115 MHz for Signals #3-4.



(c) CFOs of -5.115 MHz for Signal #3 and 5.115 MHz for Signal #4.

Fig. 4. Spectra of the new signals in the L6 band with selective CFO.

B. Signals with Selective CFO

We assume that f_s is 20.46 MHz which is the least common multiple of the minimum sample frequencies of the four new signals, 1.023 MHz, 10.23 MHz, 4.092 MHz, and 20.46 MHz. With the proposed selective CFO scheme, the available CFOs are ± 5.115 MHz. Fig. 4 shows the PSDs of the four new signals with different selctive CFOs. Figs. 4(a) and 4(b) show the cases where an identical CFO of 5.115 MHz and -5.115 MHz is respectively applied to the selected orthogonal-phased signal pair whilst Fig. 4(c) shows the case where the selected two signals are frequency shifted in opposite directions: -5.115 MHz for the BOC(2, 2) signal and 5.115 MHz for the BOC(10, 5) signal. It is obvious that we can also apply CFOs of 5.115 MHz and -5.115 MHz to the BOC(2, 2) and BOC(10, 5) signals, respectively.

It should also be noted that $c_I(t) + jc_Q(t)$ in (2) is equivalent to the discrete-time samples of the ideal complex offset carrier $e^{j2\pi\Delta f t}$ modulated with a rectangular pulse. Therefore, the PSDs with the proposed selective CFO scheme gradually decrease as the frequency grows distant from the band center. For an example of BOC(10, 5) signal, we can see in Fig. 5 that one of the two mainlobes near a band edge has a reduced PSD which slightly inclines toward the band center. Furthermore, we can also observe that the out-of-band PSD in the shaded area in Fig. 5 is decreased with the proposed scheme. It is thus expected that the transmit filter design becomes feasible compared with the typical CFO scheme in (1).

IV. Conclusions

We proposed a scheme to apply CFOs to a subgroup of signals for a new navigation satellite system. The selective CFO scheme can reuse the same CEM scheme as that without CFO. It has low implementation complexity for the signal generator and the channel filter. The proposed scheme is expected to be effective in designing a new navigation satellite signals for a frequency band where the existing legacy signals are asymmetrically distributed in spectrum.

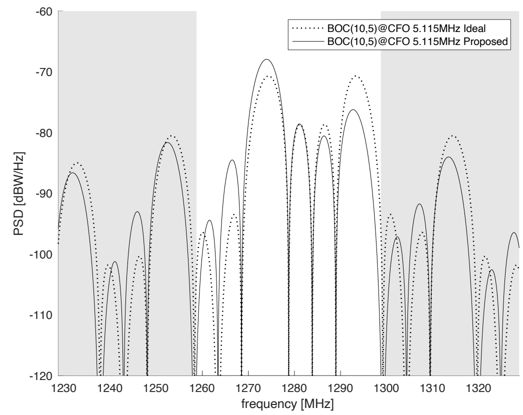


Fig. 5. PSDs of BOC(10, 5) with the typical and the proposed CFO schemes.

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