# A New Receiver Structure for Performance Enhancement in CSS

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**Abstract:** We propose a new receiver structure for chirp spread spectrum (CSS) based on the characteristics of the CSS signals which are alternatively transmitted in low and high band in order to improve detection performance. The conventional channel filter performs the filtering of entire signal bandwidth in a passband, but there happens a problem that excessive noise in neighboring sub-band is added while one of signals in two sub-bands is received. The dual-band filtering method proposed in this letter is based on two filters which are designed to be matched well with alternatively received CSS signals and excludes the undesired noise. Simulation result shows that the proposed method has better bit error rate (BER) performance about 1.6dB than the conventional one.

## 1. Introduction

IEEE 802.15 low rate alternative PHY Task Group (TG 4a) for Wireless Personal Area Networks (WPANs) standardizes a new technique whose objective is in providing low rate communications, high precision ranging/location capability (1 meter accuracy and better), ultra low power, low cost, and etc. Therefore, a new proposal which consists of Ultra Wide Band -Impulse Radio (UWB-IR) operating in unlicensed UWB spectrum and Chirp Spread Spectrum (CSS) operating in unlicensed 2.4 GHz spectrum was adopted as a new standard technique by the committee of the IEEE 802.15 TG 4a in [1]. The CSS based on ISM band uses chirp signals categorized as spread spectrum signals and can afford to get a high precision ranging because of the good correlation properties of chirp signals. It uses bi-orthogonal codes for channel coding and has low hardware complexity by using differential encoding. Also, Simultaneously Operating Piconet (SOP) for multiple users is proposed by using different combination of sub-chirps in the CSS systems as in [1].

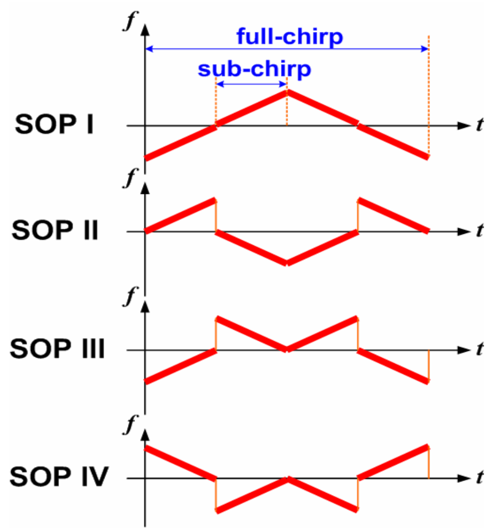
This letter shows a novel receiver structure using dual-band filtering method in order to improve the detection performance based on the characteristics of the CSS signals which are alternatively generated from low and high bands in time domain. Because the conventional channel filtering makes the entire signal bandwidth pass through, there is a problem that excessive noise in neighboring sub-band is included in the filter while one of two sub-bands is received in the system. Accordingly, if we apply the dual-band filtering method to the system of th CSS, we can reduce the excessive noise.

In this letter, section II describes overview of the CSS. Section III shows the proposed contents and section IV describes the simulation results. In section V, this letter comes to a conclusion.

## 2. Overview of the CSS

The CSS systems can be divided by three essential parts. One part is a bi-orthogonal coding block which uses 8-ary bi-orthogonal codes in 1Mbps mode and 64-ary bi-orthogonal codes at 250Kbps mode in order to obtain the block coding gain and to be robust to communication channel. Another part is a differential coding block. The CSS systems carry information to the difference of phases between successive symbols. Differential coding systems can be implemented in a less complexity than coherent encoding systems because of the channel estimator. The third part is a chirp spreading block. The CSS systems use chirp signals which are categorized as a spread spectrum signal as in [2]. The CSS systems modulate transmit data by using a phase shift keying (PSK) and spread the data by using chirp signals in order to obtain the spreading gain.

The CSS systems support 4 SOPs by using the combination of sub-chirp signals. The sub-chirp signals are designed by the up-sweeping frequency signals and the down-sweeping frequency signals in two sub bands (high and low), respectively. 4 sub-chirps are assigned in the different positions in each piconet and those different combinations of the sub-chirp signals minimize the interferences among the 4 SOPs. In each piconet, 4 sub-chirps construct a full-chirp and guard times are also different. Fig. 1 shows the 4 SOPs in the CSS systems.



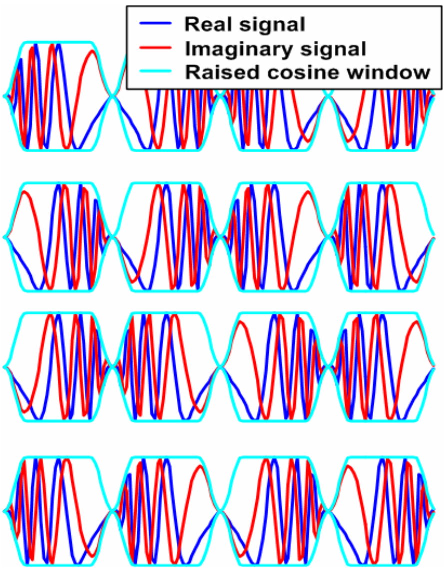



Fig 1. 4 SOPs in the CSS

## 3. Camera Ready Manuscript

Let us assume that the received signal $r(t)$ consists of the signal $s(t)$ and additive white Gaussian noise (AWGN) $n(t)$ which has zero-mean and power spectral density $\phi(f) = \frac{1}{2}N_0$ [W/Hz]. Suppose that the signal $r(t)$ passes through a filter with impulse response $h(t)$, $0 \le t \le T$, and the output of the filter is sampled at time $t = T$. The filter response to the signal and noise components can be described by (1).

$$\begin{aligned} y(t) &= \int_0^T r(\tau)h(t-\tau)d\tau \\ &= \int_0^T s(\tau)h(t-\tau)d\tau + \int_0^T n(\tau)h(t-\tau)d\tau \end{aligned} \quad (1)$$

At the sampling instant $t = T$, the signal and noise components are expressed by (2).

$$\begin{aligned} y(T) &= \int_0^T r(\tau)h(T-\tau)d\tau \\ &= \int_0^T s(\tau)h(T-\tau)d\tau + \int_0^T n(\tau)h(T-\tau)d\tau \\ &= y_s(T) + y_n(T) \end{aligned} \quad (2)$$

where $y_s(T)$ represents the signal component and $y_n(T)$ represents the noise component. Then, SNR of the filter output is defined by (3) as [2].

$$SNR = \frac{y_s^2(T)}{E\left[y_n^2(T)\right]} \quad (3)$$

Let us evaluate the denominator $E[y_n^2(T)]$.

$$\begin{aligned} E\left[y_n^2(T)\right] &= \int_0^T \int_0^T E\left[n(\tau)n(t)\right]h(T-\tau)h(T-t)\,dt\,d\tau \\ &= \frac{1}{2}N_0 \int_0^T \int_0^T \delta(t-\tau)h(T-\tau)h(T-t)\,dt\,d\tau \\ &= \frac{1}{2}N_0 \int_0^T h^2(T-\tau)\,dt \end{aligned} \quad (4)$$

In (4), we need to concentrate our attention on that the noise variance depends on not only the power spectral density of the noise but also the energy in the impulse response $h(t)$. Because the power spectral density of the noise is fixed, our goal is to reduce the energy in the impulse response $h(t)$.

The CSS signals consist of low- and high-band signals. If input signal is a high-band signal, high-band filter is designed to be operated, and if input signal is a low-band signal, low-band filter is also designed to be executed.

Fig. 2 shows noise power and bandwidth of the filter in both of the conventional channel filtering method and the dual-band filtering method. The dual-band filtering method has a smaller noise power and bandwidth in the filter than the conventional channel filtering method, because the low- and high-band filter alternatively applied to the received signals at high- and low-bands.

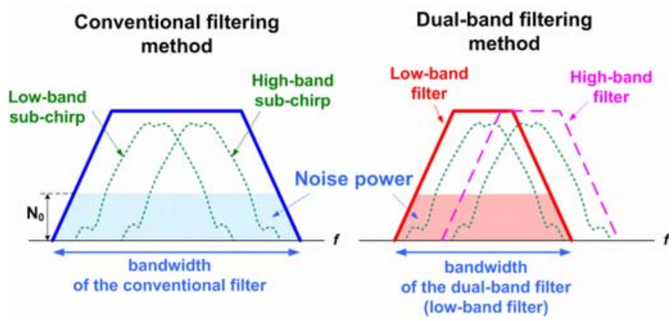



Fig 2. Conventional channel filtering method and proposed filtering method

If we evaluate the noise power of the filters, the SNR improvement can be calculated by (5).

$$\text{SNR improvement [dB]} = 10 \times \log_{10} \frac{\text{Noise power}_{\text{conventional filter}}}{\text{Noise power}_{\text{dual-band filter}}} \quad (5)$$

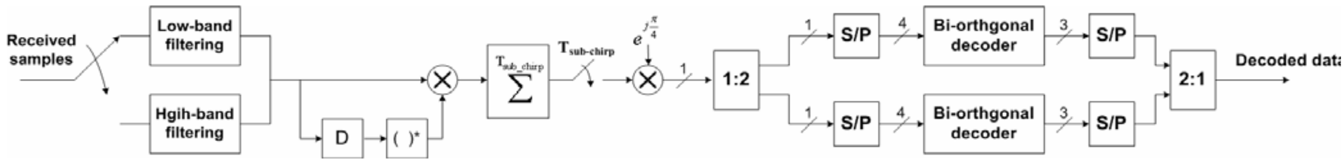



Fig. 3. Receiver block diagram of the proposed dual-band filtering method

The noise power in the filter is nearly proportional to bandwidth of the filter. Let us approximately evaluate the SNR improvement of the proposed method by using the bandwidth of the filter. Suppose that we design the bandwidth of the filter as same as the bandwidth of the signal. The bandwidth of the sub-chirp signals is 7 MHz, and sub-chirp signals of high- and low-band overlap with 0.7 MHz as in [1]. Substituting those numbers for (5), we can calculate the SNR improvement of the proposed method at about 2.78 dB.

Fig. 3 shows a block diagram of the proposed receiver using dual-band filtering. If initial synchronization of the system is reasonably detected by one, the CSS receiver can alternatively apply the proposed dual-band filter to the received signals. Then, the receiver differentially decodes the filtered outputs and despreads signal energy. The signal energy is tossed to the bi-orthogonal decoder to obtain block coding gain.

## 4. Simulation Results

Before we show the simulation results, we need to consider synchronization of the receiver system. In this letter, we assume that the synchronization is perfect.

The BER and PER simulations of the proposed and the conventional channel filtering method was performed by using the Kiser-window filter in [2] which has 23 taps and 11 taps, respectively. This means that the hardware complexity of the proposed method was similar to that of the conventional method and we only compare the BER and PER performances of the proposed method with that of conventional method. Though an additional control logic that decides which one of the channel filters between high- and low-filter is used is necessary to the proposed method, it is very simple. On the other hand, power consumption of the proposed method is slightly batter than that of the conventional method. Because the proposed method uses 11-tap filter for the received signal while the conventional method uses 23-tap filter in every time.

Fig. 4 shows the simulation results of BER performance of the proposed filtering method as compared with the conventional methods. The simulations are performed in AWGN channel. The performance of the proposed filtering method is better by about 1.6 dB at BER = $10^{-5}$ than that of the conventional method.

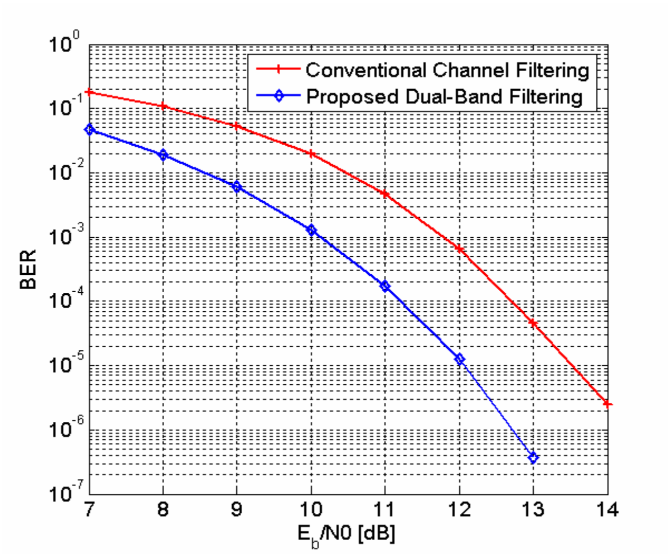



Fig. 4. BER performances of the proposed and conventional filtering method

Because the CSS systems are based on packet communication, we show PER performance of the proposed structure. The simulation results of PER performances are described in Fig. 5. The simulations are performed by using 10000 packets whose data length is 100 bytes on AWGN channel. The proposed dual-band filtering method improves the PER performance about 1.6 dB at PER = $10^{-3}$ in the same way of BER performance.

The improvements on BER and PER of the proposed method are less than that of discussed in pervious section, because the Kiser-window filter used in the simulations also impairs the transmitted signals while removes additional noise. It is necessary to find filters which fit the transmitted signals and maximally remove the additional noise.

In fact, if a matched filter is used to the CSS system, the best BER and PER performances are obtained. However, the hardware complexity of the matched filter is much lager than that of the proposed filter. The trade-off between the error performances and hardware complexity arise, however, hardware complexity and power consumption is much important factor than the error performances in application of the IEEE 802.15.4a.

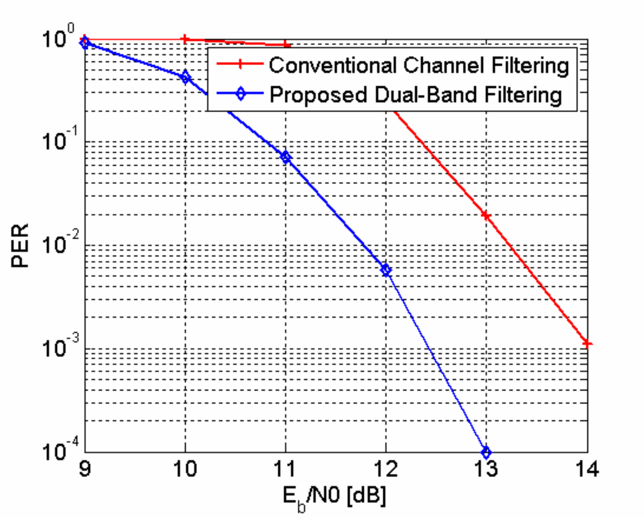


Fig. 5. PER performances of the proposed and conventional filtering method

## 5. Conclusion

A novel receiver structure using dual-band filtering for CSS was proposed. The proposed structure improved the BER and PER performances of CSS receiver, having the almost same hardware complexity in comparison with conventional one. We expect that the proposed receiver structure can be applied to the CSS systems.


## 5. Ackknowlegement

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