Interference Canceller Employing Subband Adaptive Filter for the Spread Spectrum System with Narrowband Interference

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ABSTRACT

In this paper, we propose a novel interference exciser, which requires less taps with improved interference rejection performance. In the proposed exciser, the recently introduced subband adaptive digital filter (SBADF)[1,2] is employed. It is reported that the SBADF shows improved performance to enhance the narrow band signals[1]. Thus, it is expected that the SBADF also shows the improved performance to reject narrow band signals. The computer simulations reveal that the proposed subband exciser shows improved SIR (signal to interference ratio) as compared to the conventional exciser. The performance analysis as well as computer simulation results reveal that the proposed exciser shows narrower notch bandwidth as compared to the conventional one, so the subband exciser is more suitable for the narrow band interference rejection.

I. Introduction

The direct-sequence spread spectrum (DS-SS) system can reduce the effects of the interference signal by spreading and despreading the modulated signal[3]. However, in the presence of the strong narrowband jamming signal, the interference rejection capability of the DS-SS system can be further enhanced by employing interference rejection schemes, which are often called interference excision[3-6]. Several techniques have been developed for the interference rejection. The transform-based techniques[7] and the adaptive transversal filter based techniques[5-6] are the most popular schemes. Exciser with adaptive transversal filter can reject the time varying interference with well known adaptation algorithms[8]. However, the transversal filter requires very long taps to excise the narrow band interference effectively, since it is hard to realize very narrow notch bandwidth with small taps FIR filter[1]. Thus, the conventional transversal filter may excise the information signals as well as the interference signals.

Recently, the subband adaptive digital filter (SBADF) which employs subband decomposition has been introduced[1]. One of the advantages of the SBADF is that the SBADF can be easily implemented by parallel processing. Also, the subband structure provides less correlated signals to the adaptive filters, compared to the conventional full band adaptive digital filters (FBADF), which enhances the convergence behaviors. Moreover, it is reported that the SBADF shows comparable performance as FBADF with reduced number of filter taps[9,10]. Thus, in this paper, we propose a novel interference exciser, which requires less taps with improved interference rejection performance. Recently, it is reported that the SBADF shows improved performance to enhance the narrow band signals[1]. Thus it is expected that the SBADF also shows the improved performance to reject narrow band signals. Not only computer simulations but also analysis reveal that the proposed subband exciser shows much narrower notch bandwidth as compared to the conventional one.

II. Narrowband interference exciser

In some communication environment such as

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military communications, the intentional jamming signal generated by enemy can significantly degrade the communication performance. In many cases, the jamming signal is narrow band such as tone signal whose frequency lies in the passband of the communicating signal[3]. To alleviate the narrowband interference, the spread spectrum technique such as direct sequencing spread spectrum (DS-SS) can be employed. The direct-sequence spread spectrum (DS-SS) system can reduce the effects of the interference signal by spreading and despreading the modulated signal[4]. However, in the presence of the strong narrowband jamming signal, the interference rejection capability of the DS-SS system can be further enhanced by employing interference rejection schemes, which are often called interference excision[3-6]. Fig. 1 shows the schematic diagram of the direct sequence spread spectrum system with interference exciser. The modulated information symbols are spreaded by code pulse, and in the receiver the exciser is inserted in front of the despreading circuits. Fig. 2 shows the interference exciser employing adaptive transversal filter[3]. In Fig. 1 (b), the received signal s(t), which is corrupted by strong narrowband interference, is inserted to the integrated and dump circuits and sampled at the Chip rate R_c. The sampled signal x_k, which is the input signals to the exciser is modeled as [3]

$$x_k = d_k + V\cos(\Omega k T_c + \theta) + n_k \quad (1)$$

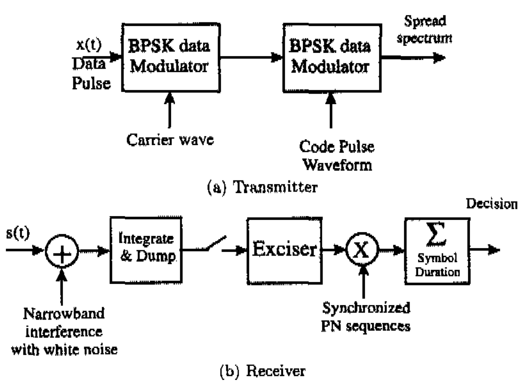

Fig. 1 Direct sequence spread spectrum system

where, d_k, n_k, V, Ω, θ, T_c are the spreaded information signal, white noise, amplitude, frequency and phase of interference signal and Chip duration, respectively. In Fig. 2, the adaptive filter predicts the current symbol x_k using forward and backward input signals. More precisely, the predicted input $\widehat{x_k}$

$$\widehat{x_k} = \sum_{n=1}^{N} a_n x_{k-n} + \sum_{n=1}^{N} a_{-n} x_{k+n}, \quad (2)$$

where $\{a_n, a_{-n}\}$ is the two-sided adaptive filter coefficient and N is the number of adaptive filter taps. As in the adaptive line enhancer (ALE), the output of the predictor is the narrowband signals. In Fig. 2, the output of the exciser y_k is

$$\begin{aligned} y_k &= x_k - \widehat{x_k} \\ &= x_k - \left(\sum_{n=1}^{N} a_n x_{k-n} + \sum_{n=1}^{N} a_{-n} x_{k+n} \right), \end{aligned} \quad (3)$$

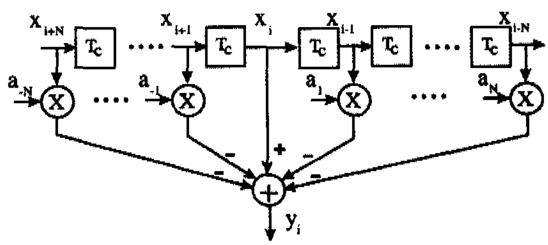

Fig. 2 Interference exciser with adaptive transversal filter

where $\widehat{x_k}$ is the estimate of the interference signal. Thus, the output of the transversal exciser can suppress the narrowband signal[3]. The optimum coefficient a_{-N}^{opt}, a_{-N+1}^{opt}, $\cdots$, a_N^{opt} can be found by batch processing[4] or iterative scheme[3]. The interference rejection performance can be evaluated by $SNR_{antijamming}$ defined as

$$SNR_{antijamming} = \frac{V^2/2}{E[y_k^2]} \quad (4)$$

Although, the transversal filter can remove most of the interference, the transversal filter requires very long taps to excise the narrow band interference effectively, since it is hard to realize very narrow notch bandwidth with small taps FIR filter[1]. Moreover, the conventional transversal filter may excise the information signals as well as the interference signals, since most of the finite adaptive filter shows excessive notch bandwidth for the narrowband interference. Thus, in this paper, we propose a novel interference exciser, which requires less taps with improved interference rejection performance. The proposed exciser exploit both time and frequency analysis of the input signal which will be detailed described in the following section.

Ⅲ. Exciser with subband adaptive digital filter

Since the introduction of the LMS algorithm by Widrow and Hoff, the adaptive digital filter has been widely used for various applications. Although the LMS algorithm is very simple, its major defect is the degraded performance for correlated input signals[11]. Hence, various structures and algorithms have been proposed to enhance the performance of the LMS algorithm, one of which is the subband adaptive digital filter (SBADF)[9,10]. Fig. 3 shows the two band SBADF where x(n), d(n) is the input and desired signal and $H_0(z)$, $H_1(z)$ is the lowpass and highpass analysis filter bank which is generally implemented by QMF (quadrature mirror filterbank)[12]. The basic relation between $H_0(z)$ and $H_1(z)$ is

$$H_1(z)=H_0(-z). \tag{5}$$

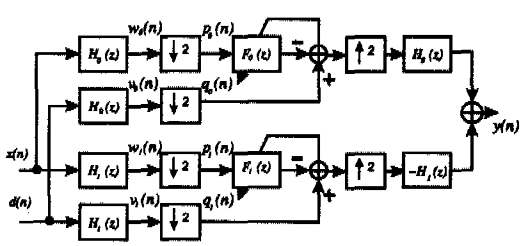

Fig. 3 Two band subband adaptive filter

In Fig. 3, $\downarrow 2$, $\uparrow 2$ is the 2:1 decimation, 1:2 interpolation, respectively. In Fig. 3 $F_0(z)$, $F_1(z)$ is the adaptive filter for the lowerband and upperband, respectively. The input for each subband adaptive filter is $p_0(n)$, $p_1(n)$ and the desired signal for each adaptive filter is $q_0(n)$, $q_1(n)$, respectively. One of the most important advantages of the SBADF is that the subband structure provides less correlated signals to the adaptive filters, compared to the full band adaptive digital filters (FBADF)[9,10]. Also, since lower order filters at lower rates can be employed for the subband signal, the computational complexity is also reduced. Another advantage is that the SBADF can be easily implemented by parallel processing, because each subband filters can be adapted independently. Also, different adaptation schemes can be employed for each subband, providing more flexibilities[10].

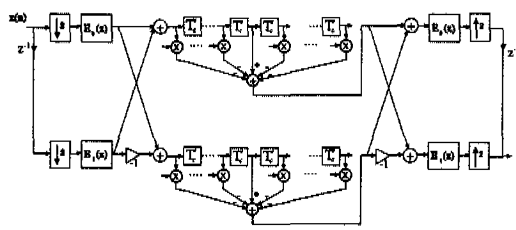

Fig. 4 Subband adaptive interference exciser ($T_c'=2T_c$)

Recently, it is reported that the subband adaptive filter shows improved performance for the adaptive line enhancer[1]. More precisely, it is shown in[1] that the subband digital filter can approximate an optimum filter with sharp frequency response, which is generally difficult for the conventional adaptive FIR filter with finite filter taps. Thus, it is expected that the SBADF shows improved performance for the narrow band signal extraction. Fig. 4 shows the schematic diagram of the proposed subband adaptive interference exciser. In Fig. 4, the 2-band polyphase subband decomposition scheme is employed[12]. The polyphase structure is known as an efficient implementation of the QMF filterbank depicted in Fig. 3. The analysis filter $H_0(z)$ can be represented by

$$H_0(z) = E_0(z^2) + z^{-1}E_1(z^2), \quad (6)$$

which is known as type-I polyphase decomposition[12]. From (6),

$$H_1(z) = E_0(z^2) - z^{-1}E_1(z^2). \quad (7)$$

We can find from (6) and (7) that there are some common factors between QMF filter banks. Thus, we can obtain efficient SBADF as depicted in Fig. 4, where the required total multiplication is N for N tap analysis filter bank [13]. In each subband, the two-sided prediction filters depicted in Fig. 2 predict and reject the interference signals. Comparing to the conventional transversal filter, the adaptive filters in each subband operates at a lower rate. Moreover, the prediction capability of the narrowband signal can be enhanced, since the SBADF has finer the spectral resolution for each subband[1]. It can be easily inferred as in subband ALE[1] that the subband which do not contain narrow band interference automatically transmit all of the information signal. More precisely, the optimum filter for the prediction filter satisfies the Wiener equation given by,

$$\sum_{k=-N, k\neq 0}^{N} r(l-k)a_k^{opt} = r(l), \quad l=-N,\cdots,-1,1,\cdots,N \quad (8)$$

where r(m) is the correlation function given by

$$r(m) = E\{x_i x_{i-m}\}. \quad (9)$$

In the subband which do not has interference, the input to the subband exciser is the spreaded modulated signal. Since the spreaded signal is assumed to be white, $r(m) = \delta(m)$. Thus, the optimum filter a_k^{opt} satisfy

$$\begin{pmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{pmatrix} \begin{pmatrix} a_{-N}^{opt} \\ a_{-N+1}^{opt} \\ \vdots \\ a_N^{opt} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{pmatrix} \quad (10)$$

Thus, the coefficients of the subband which does not contain the interference signal converge to zero. Thus, from (4), the output of the prediction filter y_k is the same as x_k. Then, the subband which has the interference signal predict and remove the interference signal. As in ALE[1], it is expected that the prediction capability for the subband exciser outperforms conventional fullband scheme, since it is more convenient to find and reject the narrowband component in subband rather than in full band.

Ⅳ. Performance analysis

In this section, the performance of the subband exciser is analyzed by employing the subband correlation function[1]. Especially, the frequency response of the optimum subband exciser is derived and compared to the conventional one. The optimum filter for the conventional exciser is presented in[5]. In this paper, the optimum filter for the subband exciser is derived based on the [5]. Let the input signal to the exciser depicted in Fig. 2 be

$$x_i = d_i + V\cos(\Omega iT + \theta) + n_i \quad (11)$$

where d_i, n_i, T are the spreaded information signal with power S, noise, sampling interval, respectively, and V, Ω, θ are the amplitude, frequency, and phase of the jamming signal, respectively. The adaptive filter coefficients which minimize the output error y_t in the MMSE (minimum mean squares error) sense converge to the optimum filter a_k^{opt} satisfying the Wiener equation given by

$$\sum_{k=-N, k\neq 0}^{N} r(l-k)a_k^{opt} = r(l), \quad l=-N,\cdots,-1,1,\cdots,N \quad (12)$$

where r(m) is the correlation function

$$r(m) = E\{x_i x_{i-m}\}. \quad (13)$$

In (11), since the spreaded information signal d_t is white, the correlation function r(m) is

$$r(m) = (S+\sigma_n^2)\delta(m) + J\cos(m\Omega T), \quad (14)$$

where J is the jamming signal power[5]. As shown in[5], the optimum filter satisfying the Wiener equation is

$$a_k^{opt} = 2A\cos(k\Omega T), \tag{15}$$

where A is

$$A = \frac{J}{2(S+\sigma_n^2) + J(2N-1+\frac{\sin(2N+1)\Omega T}{\sin \Omega T})}. \tag{16}$$

The frequency response of the exciser is

$$H(\omega) = e^{-j\omega NT}(1 - \sum_{k=-N, k\neq 0}^{N} a_k^{opt} e^{j\omega kT}). \tag{17}$$

The optimum filter for the subband exciser can be derived with the subband correlation function.

Recently, it is shown that the subband correlation can be derived by using fullband correlation function[1]. Let us consider the 2-band subband adaptive digital filter depicted in Fig. 3. Let $R_{p_0p_0}(n), R_{p_1p_1}(n)$ be correlation function for the lowerband and upperband signal, respectively. Then from[1],

Theorem 1: Let us consider 2-band SBADF in Fig. 3. The autocorrelation function for the lower band signal $R_{p_0p_0}(n)$ can be expressed in terms of the input autocorrelation function $R_{xx}(n)$, given by

$$R_{p_0p_0}(n) = \frac{1}{2}\{c(n) + d(n)\}, \tag{18}$$

where

$$\begin{aligned} c(n) &= R_{xx}(2n) \\ d(n) &= \sum_{k=-\infty}^{\infty} R_{xx}(2k-1)\psi(n-k) \\ \psi(n) &= \frac{2}{\pi}\frac{(-1)^n}{1+2n}. \end{aligned} \tag{19}$$

Similarly, the autocorrelation function for the upper band input signal is given by

$$R_{p_1p_1}(n) = \frac{1}{2}\{c(n) - d(n)\}. \tag{20}$$

Thus from (15)

$$\begin{aligned} R_{p_0p_0}(m) &= \frac{1}{2}\{(S+\sigma_n^2)\delta(2m) + J\cos(2m\Omega T) \\ &+ \sum_{k=-\infty}^{\infty}\{(S+\sigma_n^2)\delta(2k-1) \\ &+ J\cos((2k-1)\Omega T)\}\psi(m-k)\} \\ R_{p_1p_1}(m) &= \frac{1}{2}\{(S+\sigma_n^2)\delta(2m) + J\cos(2m\Omega T) \\ &- \sum_{k=-\infty}^{\infty}\{(S+\sigma_n^2)\delta(2k-1) \\ &+ J\cos((2k-1)\Omega T)\}\psi(m-k)\} \\ \psi(n) &= \frac{2}{\pi}\frac{(-1)^n}{1+2n}. \end{aligned} \tag{21}$$

By solving the subband Wiener equation derived by (21), we can get the optimum coefficients for the subband exciser given by

$$\begin{aligned} &\sum_{k=-N, k\neq 0}^{N} R_{p_0p_0}(l-k)a_k^{opt\,0} \\ &= R_{p_0p_0}(l), \quad l=-N,\cdots,-1,1,\cdots,N \\ &\sum_{k=-N, k\neq 0}^{N} R_{p_1p_1}(l-k)a_k^{opt\,1} \\ &= R_{p_1p_1}(l), \quad l=-N,\cdots,-1,1,\cdots,N \end{aligned} \tag{22}$$

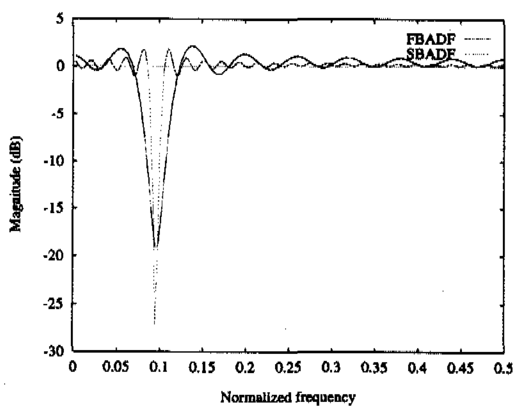

Fig. 5 Frequency response of the exciser based on analysis

where $a_k^{opt\,0}, a_k^{opt\,1}$ are the optimum filter for the lower and upper band, respectively. The frequency response of the conventional and the subband exciser can be derived by (17). Fig. 5 shows the frequency response of the conventional and the subband exciser, where the filter length $N=16$, $S=1$, $\sigma=1$, $J=1$, $\Omega=0.1$, $T=1$.We can find that the subband exciser shows narrower notch bandwidth. Thus, it is expected that the subband exciser can reject less useful information signals.

V. Computer simulation

In the simulation, BPSK modulated signal is transmitted through Gaussian noise channel with strong jamming signal. The Chip rate R_c is 4 times that of the symbol rate R. The spreading code is obtained from the shift register output as in[14]. After BPSK modulation, the information signal is modulated by the spreading code and inputed to the pulse shaping filter. The received signal which is corrupted by strong narrow band jamming signal is demodulated. To maximize the output E_b/N_0, the matched filter is employed after demodulation. And the output of the matched filter is sampled at the Chip rate. The sampled signal is the input signal to the interference exciser. In the simulations, the conventional and the proposed excisers are compared. Fig. 6 and Fig. 7 show the interference estimation of each exciser, where the E_b/N_0 is 0 dB and the E_b/I_0 is 1.5 dB. We can find that the proposed exciser can estimate the interference more precisely than the conventional one. This results can be explained as in subband ALE[1]. That is, the SBADF can more easily approximate narrow band frequency response than the FBADF. To substantiate this fact, Fig. 8 shows the frequency response of exciser with 32 tap adaptive filters. We can find that the subband exciser has sharper notch frequency than the conventional one as is also expected in the performance analysis. Now let us consider the interference rejection performance as $SNR_{antijamming}$ defined as

$$SNR_{antijamming} = \frac{Jamming\ signal\ power}{Estimation\ error\ power}. \quad (23)$$

Fig. 9 shows the $SNR_{antijamming}$ for each exciser, where the adaptive filter taps for the SBADF and FBADF is 8 and 16 respectively, and 16 tap QMF filter banks are employed for the SBADF. We can find that the subband exciser shows 1-2 dB higher $SNR_{antijamming}$ for almost every E_b/N_0 ranges.

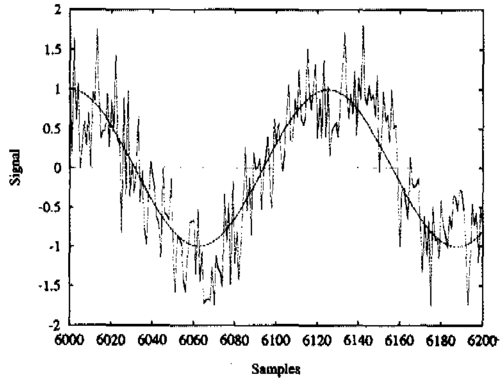

Fig. 6 Interference estimation with conventional exciser ($E_b/I_0 = 1.5dB$)

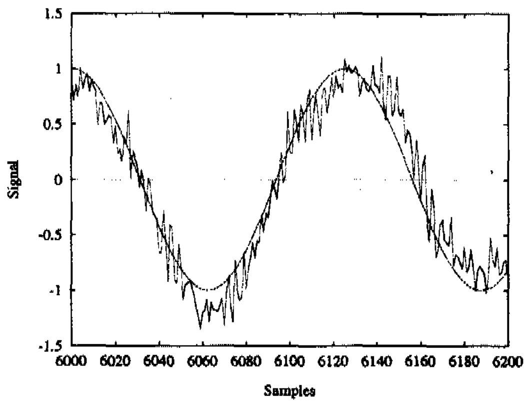

Fig. 7 Interference estimation with subband exciser ($E_b/I_0 = 1.5dB$)

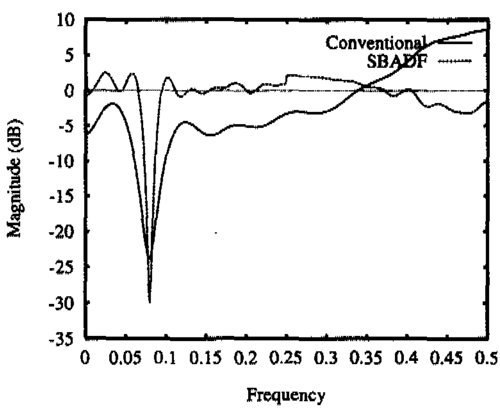

Fig. 8 Frequency response of the exciser with 32 tap filter

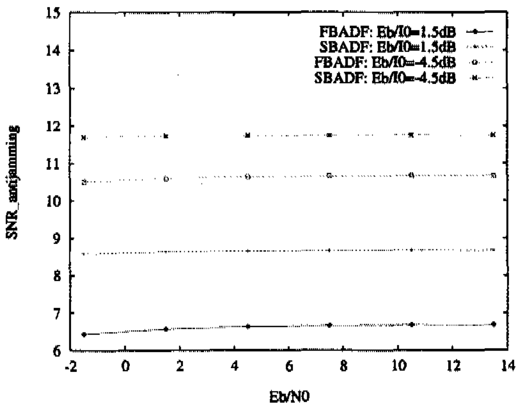

Fig. 9 Performance of the exciser

V. Concluding Remarks

The subband exciser which shows better interference rejection performance than the conventional exciser has been proposed in this paper. As in the ALE, when the exciser input has very narrow notch spectrum, the performance of the SBADF generally outperforms the FBADF. This framework of the SBADF can be applied any other applications where spectral resolution is important. Recently, the exciser with filterbank is reported to have good performance[15]. In [15], the interference is rejected in time-frequency domain employing filter banks. However, the rejection scheme in [15] is not adaptive. But, the proposed exciser employs frequency analysis using subband technique as well as time domain technique with adaptive filter. Thus, the proposed subband exciser can be classified as an adaptive time-frequency domain interference rejection scheme.

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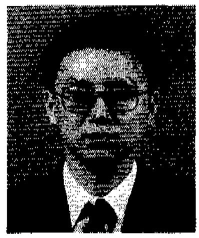

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