Hardware Design of Filter Bank-Based Narrowband/Wideband Interference Canceler for Overlaid TDMA/CDMA Systems

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Abstract - An adaptive interference canceler, which we have proposed for co-existence problem of TDMA/CDMA systems can jointly cancel both wideband interference (CDMA signals in terms of TDMA signals) and narrowband interference (TDMA signals in terms of CDMA signals). The canceler is implemented with a 63rd-order IIR-based multirate filter bank, so it can digitally process all the signals in baseband with less computational cost, and can efficiently cope with narrowband signals with various bandwidths (transmission rates), making full use of "multiresolution analysis capability" of multirate filter bank.

In this paper, we describe an experiment system for the multirate filter bank-based narrowband/wideband interference canceler, and give the detailed hardware design of the canceler with fixed-point DSPs (digital signal processors).

I. Introduction

DS-CDMA (direct sequence code division multiple access) system has an attractive feature of capability to share frequency band with narrowband communication systems without intolerable degradation of either system's performance. Now, CDMA overlay and narrowband interference cancellation are hot topics of research. On the other hand, in software-based wireless multimedia communications system, different access schemes can be employed in different cells, according to user's QoS (quality of service) and channel condition [1]. In this case, narrowband signals such as TDMA (time division multiple access) signals suffer from inter-cell narrowband and wideband interference, whereas wideband CDMA signals suffer from inter-cell narrowband interference and inter-cell and intra-cell wideband interference. These situations are all modeled as a co-existence problem of TDMA/CDMA systems where narrowband signals and wideband signals share the same frequency band [2]. A key issue is how to separate both signals with less distortion and less impairment.

We have proposed [3] an adaptive interference canceler for the co-existence problem of TDMA/CDMA systems, which is implemented with a multirate filter bank (MRFB) [4]. This canceler has the following advantages:

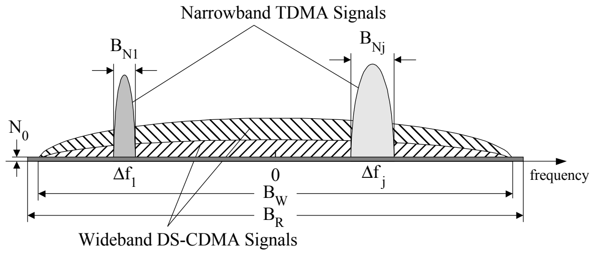


Fig. 1 Power Spectrum of Frequency Sharing TDMA/CDMA System

- it can digitally process all the signals in baseband,
- it can efficiently cope with narrowband signals with various bandwidths (transmission rates), making full use of "multiresolution analysis capability" of MRFB.

In addition, a MRFB designed with IIR (infinite impulse response) filters can introduce a low computation cost, as compared with a FIR (finite impulse response) approach.

We have carried out a hardware design of the multirate filter bank-based narrowband/wideband interference canceler with fixed-point DSPs and have developed an experiment system for it. In this paper, we describe the experiment system for the multirate filter bank-based narrowband/wideband interference canceler, and give the detailed hardware design of the canceler. Finally, we give the hardware experimental results.

II. Frequency Sharing TDMA/CDMA Model

We assume an uplink channel, where there are M_W wideband DS-CDMA signals and M_N narrowband TDMA signals. Fig.1 shows the power spectrum of the received signal at a base station. With the equivalent low pass expression, it is written as

$$R(f) = \sum_{i=1}^{M_W} B_i^W(f) + \sum_{j=1}^{M_N} B_j^N(f) + N(f) \ , \qquad (1)$$

where $B_i^W(f)$, $B_j^N(f)$ and $N(f)$ are the power spectra of the wideband and narrowband signals and the additive Gaussian noise, respectively.

If the root Nyquist filter is employed as a baseband pulse shaping filter in narrowband and wideband systems,

$B_i^W(f)$ and $B_j^N(f)$ are written as

$$B_i^W(f) = \begin{cases} P_i \left| S_W(f) \right|^2 ; \ |f| \le B_W/2 \\ 0 ; \ \text{otherwise} \end{cases}, \tag{2}$$

$$B_j^N(f) = \begin{cases} P_j \left| S_N(f - \Delta f_j) \right|^2 ; \ |f - \Delta f_j| \le B_N/2 \\ 0 ; \ \text{otherwise} \end{cases}, \tag{3}$$

where Δf_j is the carrier frequency of the *j*-th narrowband signal, B_W and B_N are the bandwidths of the wideband and narrowband signals, respectively, P_i and P_j are the received power of *i*-th wideband signal and the *j*-th narrowband signal, respectively. Furthermore, $S_*(f)$ is the normalized frequency response of the root Nyquist filter given by

$$S_*(f) = \begin{cases} \sqrt{T_*} \ ; \ 0 \le |f| \le (1-\alpha_*)/2T_* \\ \sqrt{\dfrac{T_*}{2}\left[1 - \sin\left\{\dfrac{\pi T_* \left(|f| - 1/2T_*\right)}{\alpha_*}\right\}\right]} \\ \quad ; \ (1-\alpha_*)/2T_* \le |f| \le (1+\alpha_*)/2T_* \\ 0 ; \ \text{otherwise} \end{cases}, \tag{4}$$

where * means W or N_j, T_* and α_* are the symbol duration and roll-off factor, respectively. Finally, defining B_R as the bandwidth determined by the front-end band pass filter of receiver, $N(f)$ is written as

$$N(f) = \begin{cases} N_0 \ ; \ |f| \le B_R/2 \\ 0 ; \ \text{otherwise} \end{cases}, \tag{5}$$

where N_0 is the spectral density of the AWGN.

III. Filter Bank-Based Narrowband/Wideband Interference Canceler

A multirate filter bank can analyze the input signal with different frequency resolutions at the same time, adaptively changing the resolution in any part of the frequency band. Fig.2 shows the multirate filter bank. The two-channel multirate filter bank needs to satisfy the following conditions:

$$H_0(z) = H_1(-z), \tag{6}$$

$$F_0(z) = j^N H_0(z), \tag{7}$$

$$F_1(z) = -j^N H_1(z), \tag{8}$$

where $H_0(z)$ and $H_1(z)$ are a filter pair in the analysis filter bank and $F_0(z)$ and $F_1(z)$ are a filter pair in the synthesis filter bank, respectively. We have discussed a FIR approach, which makes it possible to have the group delay

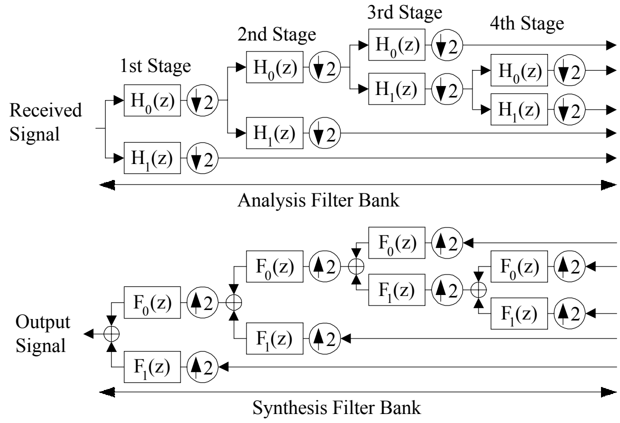
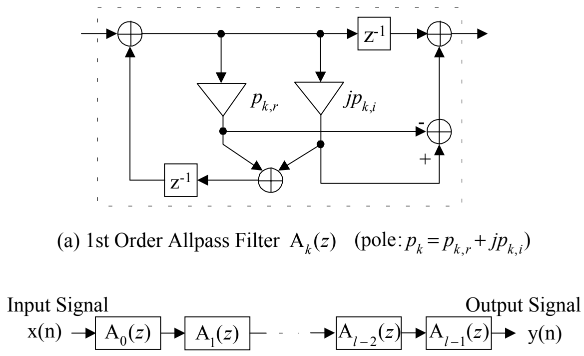


Fig. 2 Multirate Filter Bank



(a) 1st Order Allpass Filter $A_k(z)$ (pole: $p_k = p_{k,r} + jp_{k,i}$)

(b) *l*-th Order Allpass Filter

Fig. 3 IIR Filter

perfectly flat but impossible to have the magnitude response flatter in the passband with shorter filters. In other words, flatter magnitude response requires longer FIR filters, so it results in larger processing delay. Here instead, we take an IIR approach. In this case, the two-channel multirate filter bank satisfies the following conditions moreover:

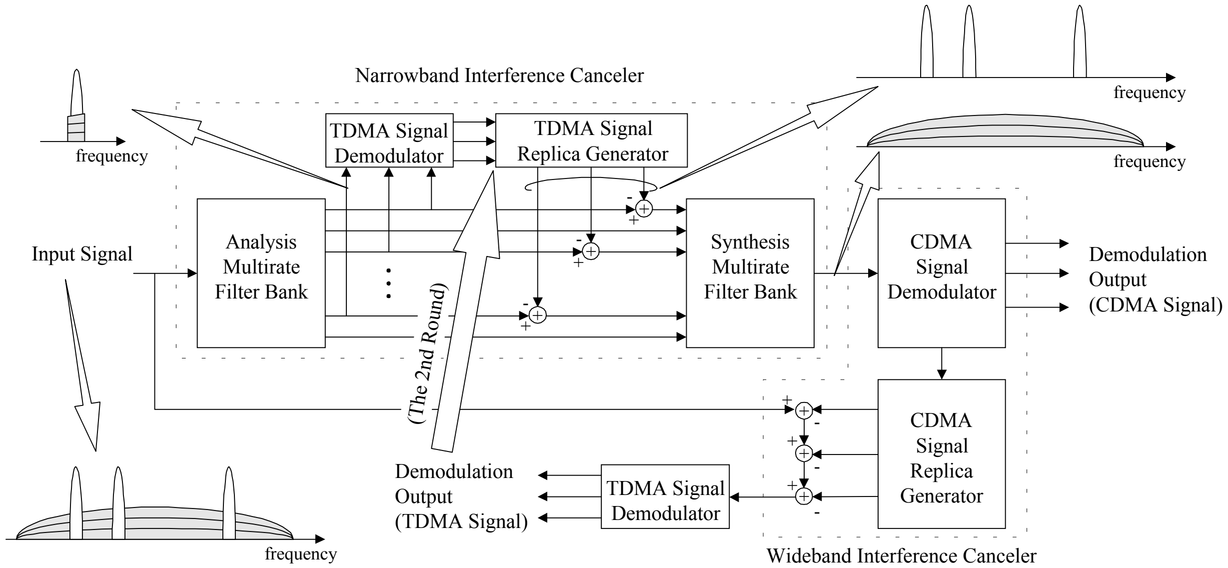
$$H_0(z) = A(jz), \tag{9}$$

$$A(z) = A_0(z^2) + z^{-1} A_1(z^2), \tag{10}$$

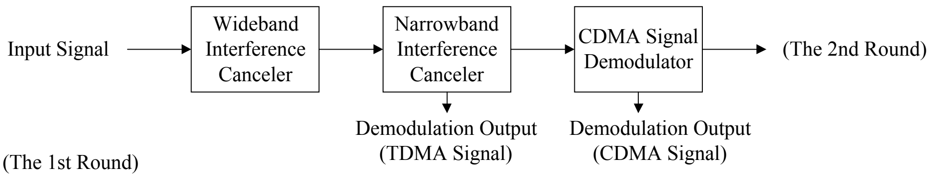
$$A_i(z) = \prod_{k=0}^{l_i - 1} A_{i,k}, \ (i = 0,1) \tag{11}$$

$$A_{i,k}(z) = \frac{z^{-1} - p_{i,k}^*}{1 - z^{-1} p_{i,k}}, \tag{12}$$

As shown in Fig.3, the filter $A_i(z)$ is a l_i-stage cascade of allpass filters with poles $p_{i,k}$ (i = 0, 1).
For IIR filters, it is very difficult to obtain flat group delay property. So taking Moore's model reduction method [5], we design a 63rd-order IIR filter out of a 64th-order FIR filter. Table 2 shows the poles of the obtained IIR filter. Note that the orders of these filters are almost the same, but the IIR filter has almost a half complexity in terms of the number of



(a)Algorithm 1 (The 1st Round)



(b)Algorithm 2 (The 1st Round)

Fig. 4 Block Diagram of Narrowband/Wideband Interference Canceler

complex multiplication.

Fig.4 shows the block diagram of the multirate filter bank-based narrowband/wideband interference canceler and the cancellation procedure when the power of TDMA signal is larger than that of CDMA signal (The first round):

1. the TDMA signals are temporarily demodulated with the appropriate analysis filter bank outputs,
2. the TDMA signal replicas are generated with the temporal demodulation data,
3. the TDMA signals are canceled at the appropriate synthesis filter bank inputs (narrowband interference cancellation),
4. the CDMA signals are demodulated with the synthesis filter output,
5. the CDMA signal replicas are generated with the demodulation data,
6. the CDMA signals are canceled with the received signal (wideband interference cancellation),
7. the TDMA signals are demodulated with the resultant signal.

IV. Hardware Construction and Specifications of the Experiment System

Fig.5 shows the construction of the experiment system and Fig.6 shows its appearance. This system consists of two parts. The first part is a host terminal, which is a work station. The host terminal controls a DSP unit (digital signal processing unit), which is explained below and has functions generating 16-bit A/D converted signals that are transmitted to the DSP unit and measuring the BER (bit error rate). The second part is the DSP unit that consists of one Interface board and three DSP boards (digital signal processing boards). Table 1 shows the hardware specifications of the Interface board and the DSP board. The DSP unit is connected with the host terminal using an IEEE1284 parallel port. The Interface board has memory that all CPUs (central processing units) on DSP unit such as DSP can access in common, but not at the same time. The DSP boards are divided into two types by roles. We call one master DSP board and another slave DSP board. The master and slave DSP boards are the same hardware design and we tell the master DSP board from the slave by changing simply their design of CPLD (complex programmable logic device), which is a reconfigurable device. The master DSP board, which is only one in the DSP boards, controls a flow calculating the adaptive canceler and gives a command to slave DSP boards that they start digital signal processing. The master DSP board also manages the common memory area, so it allocates memory out of common memory area to each slave DSP board giving a command. The slave DSP board

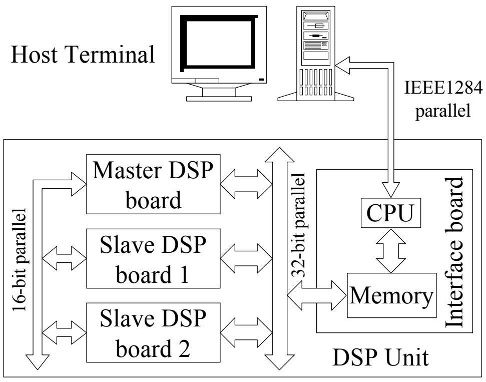


Fig. 5 Construction of Experiment System

calculates the following digital signal processes,

- analysis filter bank,
- synthesis filter bank,
- TDMA signal demodulation,
- CDMA signal demodulation,
- TDMA signal replica generation,
- CDMA signal replica generation.

Note that these are calculated with the 16-bit fixed-point operations.

The demodulation data of TDMA or CDMA signal are temporarily stored in common memory and they are returned to the host terminal finally.

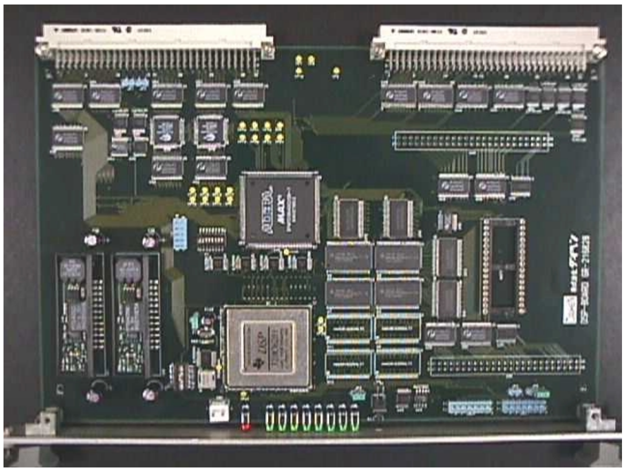
V. Experimental Results

Fig.7 shows the BER performance of the proposed canceler obtained from experiment simulation: the BER versus E_b/N_0 . Here, we assume a situation as a channel model where one TDMA signal and one CDMA signal are sharing the same frequency band and the following assumptions are made:

- the CDMA signal is based on QPSK/coherent detection format (α_W = 0.5), whereas the TDMA signal based on DQPSK/differential detection format (α_N = 0.5),
- the center frequency of TDMA signal is located at that of bandpass filters constructed by the six-stage multirate filter bank,
- the bandwidth ratio of TDMA to CDMA signals is 1/64,
- the power ratio of TDMA to CDMA signals is 10[dB], so the TDMA signal (narrowband interference) should be first canceled,

Fig.7 shows that the obtained BERs are excellent and they are closed to the lower bounds in TDMA and CDMA cases, so the developed canceler can do a good cancellation of narrowband and wideband interference.

(a) Experiment System



(b) DSP board

Fig. 6 Appearance of Experiment System

Table 1 Hardware Specifications of DSP Unit

Interface board	
CPU	HITACHI SH7032 20MHz
Memory	1MB (local use) 2MB (common use)
I/O	32-bit parallel 8-bit parallel (IEEE1284)
Connector	DIN96-pin D-SUB25-pin

DSP board	
CPU	TI TMS320C6201B 200MHz
Memory	2MB
I/O	32-bit parallel 16-bit parallel
Connector	DIN96-pin

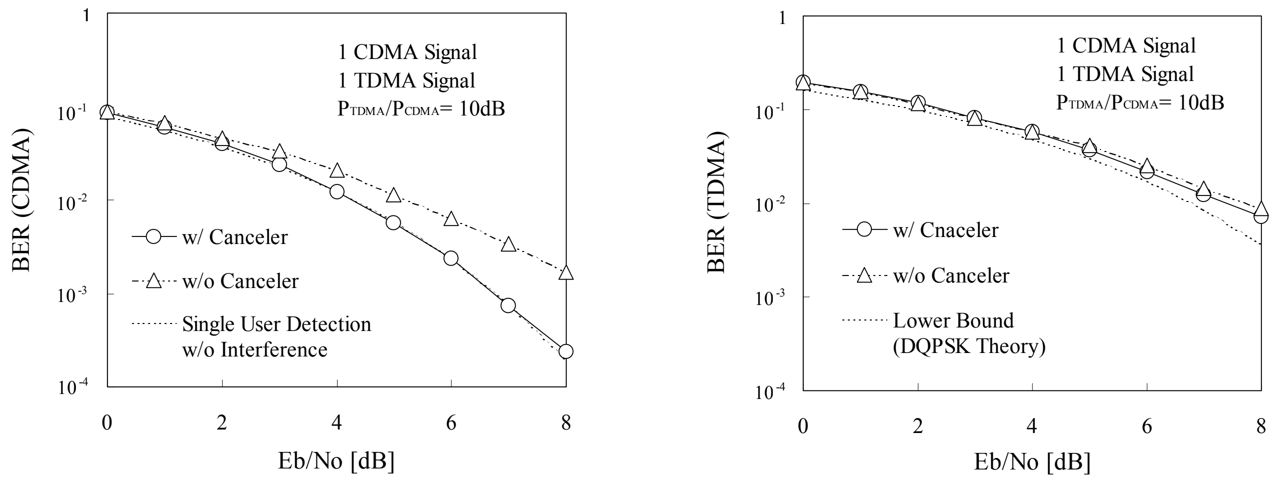


Fig. 7 BER versus Eb/No

VI. Conclusion

We have developed the experiment system for multirate filter bank-based narrowband/wideband interference canceler. In this paper, we have described detailed hardware design and have shown the developed canceler can nicely separate both TDMA and CDMA signals.

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Table 2 Poles of 63rd-order IIR filter

k	$p_{0,k}$
0	-7.502326*e*-1+*j*8.944929*e*-2
1	-7.502326*e*-1-*j*8.944929*e*-2
2	-5.866216*e*-1+*j*3.977001*e*-1
3	-5.866216*e*-1-*j*3.977001*e*-1
4	-3.771372*e*-1+*j*5.767653*e*-1
5	-3.771372*e*-1-*j*5.767653*e*-1
6	-1.265871*e*-1+*j*6.668743*e*-1
7	-1.265871*e*-1-*j*6.668743*e*-1
8	1.357610*e*-1+*j*6.585962*e*-1
9	1.357610*e*-1-*j*6.585962*e*-1
10	6.521463*e*-1+*j*1.290662*e*-1
11	6.521463*e*-1-*j*1.290662*e*-1
12	5.547748*e*-1+*j*3.683493*e*-1
13	5.547748*e*-1-*j*3.683493*e*-1
14	3.740883*e*-1+*j*5.538607*e*-1
15	3.740883*e*-1-*j*5.538607*e*-1

k	$p_{1,k}$
0	-7.363794*e*-1+*j*2.427383*e*-1
1	-7.363794*e*-1-*j*2.427383*e*-1
2	-5.784493*e*-1+*j*4.891981*e*-1
3	-5.784493*e*-1-*j*4.891981*e*-1
4	-3.371568*e*-1+*j*6.726667*e*-1
5	-3.371568*e*-1-*j*6.726667*e*-1
6	-4.325774*e*-2+*j*7.473283*e*-1
7	-4.325774*e*-2-*j*7.473283*e*-1
8	2.552523*e*-1+*j*7.007379*e*-1
9	2.552523*e*-1-*j*7.007379*e*-1
10	6.820621*e*-1+*j*2.941097*e*-1
11	6.820621*e*-1-*j*2.941097*e*-1
12	5.105900*e*-1+*j*5.409718*e*-1
13	5.105900*e*-1-*j*5.409718*e*-1
14	7.423893*e*-1