Channelized Receiver with WOLA Filterbank

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Abstract: **Polyphase DFT filterbank is an efficient structure for channelized receivers, but its flexibility limited by the fixed relationship between decimating factor and channel number. In this paper, a flexible and efficient channelized receiver structure was proposed based on weighted overlap-add filterbank. In the structure, shift of input signals substitute shift of time windows. Filter coefficients are used to weight shifted signals rather than calculate convolution. DFT is employed after signal weighting, overlapping and adding. The structure is equal with polyphase DFT channelizer mathematically, but avoids its strict condition. It's a generalized form of polyphase DFT structure. Simulation results show the effectiveness of proposed structure.**

Key words: **channelized receiver, weighted overlap-add filterbank, polyphase DFT filterbank, short-time Fourier transform**

I. INTRODUCTION

Lowpass filterbank is a classic structure to construct channelized receiver. But it has been replaced by high efficient polyphase DFT (PDFT) filterbank for its calculation complexity [1]. In PDFT structure, decimation factor must equal with channel number, which means the relationship between output rate and channel width is fixed. Weighted Overlap-Add (WOLA) filterbank is a low power, low delay and flexible filterbank. Initially it is used in short time Fourier transform (STFT). In recent years, it gains wide application in subband coding, OFDM, and speech signal processing [2]-[6]. In this paper WOLA filterbank is applied to channelized receiver. It is mathematically equal with PDFT structure since they can all be deduced from lowpass filterbank. WOLA filterbank is a general form of PDFT, so it is suitable for channelizer. On the other hand, PDFT structure also can be used to realize STFT.

This paper is organized as follows: Section 2 describes the PDFT structures for channelizer. Section 3 deduces the WOLA channelizer from lowpass filterbank structure. Section 4 gives a design example to evaluate the proposed structure. Finally, section 5 concludes the paper.

II. PDFT STRUCTURE

In channelizer, wideband signals are separated into many narrowband signals. Filterbank is used to split frequency band. The conventional structure with lowpass filterbank is shown in Fig.1. Each channel is composed of three parts. Mixer transfer intermediate frequency (IF) to baseband and filter determine signal bandwidth. Decimator decrease the data rate since sub-channel width is less than original signals. Then outputs in each channel are

$$X_k(m) = \sum_{n=-\infty}^{\infty} h(mD-n)x(n)e^{-jw_k n}$$

$$= \sum_{n=-\infty}^{\infty} h(mD-n)x(n)W_K^{-kn}, \quad k = 0,1,\cdots K-1 \qquad (1)$$

where $w_k = 2\pi\frac{k}{K}$, $W_K = e^{j2\pi/K}$, K is channel number. D is decimation factor. Lowpass filterbank channelizer is low efficient because filters in each channel are equal, but they need been realized K times. In Eq.1, let [1]

$$p_i(n) = h(nK-i)$$

$$x_i(n) = x(nK+i), \qquad i = 0,1,\cdots K-1 \qquad (2)$$

Where $p_i(n)$ is polyphase filter of $h(n)$. If $D = K$, Eq.(1) becomes

$$X_k(m) = \sum_{n=-\infty}^{\infty} h(mD-n)x(n)e^{-j2\pi\frac{k}{K}n}$$

$$= \sum_{i=0}^{K-1}\sum_{r=-\infty}^{\infty} h(rK-i)x(mK-rK+i)e^{j2\pi\frac{k}{K}(rK-i)}$$

$$= \sum_{i=0}^{K-1}\sum_{r=-\infty}^{\infty} p_i(r)x_i(m-r)e^{-j2\pi\frac{k}{K}i}$$

$$= \sum_{i=0}^{K-1}[p_i(m)*x_i(m)]e^{-j2\pi\frac{k}{K}i} = DFT[p_i(m)*x_i(m)] \qquad (3)$$

The PDFT structure of channelized receiver can be obtained from Eq.3, as shown in Fig.2. Comparing conventional structure in Fig.1, decimators are transferred before filters and calculation complexity decrease. So efficiency increase K times; K filters in Fig.1 is replaced by one filter and shared in polyphase form, efficiency also increase K times. But Eq.3 is obtained on the condition $D = K$. Let sampling frequency is f_s, and then outputs rates in each channels are $f_{out} = f_s / D$, their channel width is $B = f_s / K$. D equals to K means output rate is equal with channel width, so each channel must be critical sampling. The condition limited the flexibility to design receiver system.

One way to solute the problem is interpolate $I-1$ zero samples after decimation, make $K = ID$. But interpolation filters are needed, which will increase the computation complexity. I is an integer, so K also is limited by D.

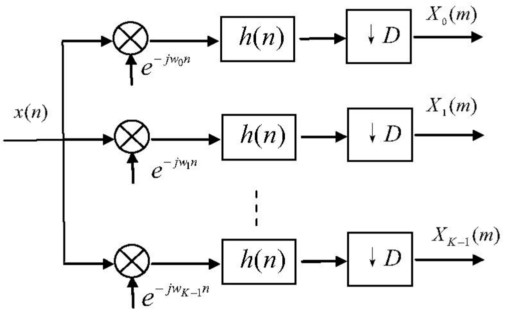


Fig.1 Lowpass filterbank channelizer

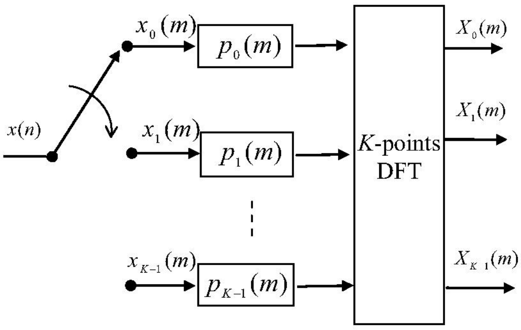


Fig.2 PDFT channelizer

III. WOLA STRUCTURE

WOLA filterbank is initially used in STFT. STFT also called windowed Fourier transform (FT). The signals are first windowed before Fourier transform, which can calculate the local spectrum. It is defined as [2]

$$STFT_x(m) = \sum_{n=-\infty}^{\infty} w^*(m-n)x(n)e^{-jwn} \tag{4}$$

Where $w^*(m-n)$ is time window, m is delay parameter of time window. Comparing Eq.1 with Eq.4, the output sequences in Eq.1 is discrete Fourier transform of $h(mD-n)x(n)$, or windowed FT of $x(n)$. $h(mD-n)$ is time window and mD is delay parameter. Real window function is conjugated symmetrical, so difference in Eq. 1 and Eq.4 is the delay parameter. In Eq.1 it must be integral times of D, when D=1, they are identical. So Eq.1 is a special STFT. On the other hand, WOLA also can be used in channelized receiver.

In Eq.1, variation of delay parameter mD leads shift of time window. It can be converted to shift of signals by variable substitution. Let $r = n - mD$ in Eq.1, we get

$$\begin{aligned} X_k(m) &= \sum_{r=-\infty}^{\infty} h(-r)x(r+mD)W_K^{-k(r+mD)} \\ &= W_K^{-kmD} \sum_{r=-\infty}^{\infty} h(-r)x(r+mD)W_K^{-kr} = W_K^{-kmD}\widetilde{X}_k(m) \end{aligned} \tag{5}$$

In above equation, let

$$\widetilde{y}_m(r) = h(-r)x(r+mD) \tag{6}$$

Then

$$\widetilde{X}_K(m) = \sum_{r=-\infty}^{\infty} \widetilde{y}(m) \tag{7}$$

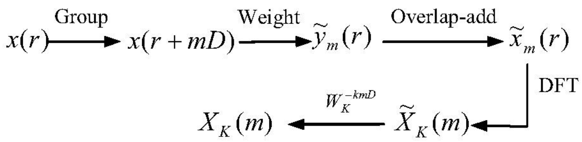
So $\widetilde{X}_k(m)$ is discrete Fourier transform of $\widetilde{y}_m(r)$. Changing m, window is invariable but signal is shifting. To calculate the discrete Fourier transform in Eq.7, we divided $\widetilde{y}_m(r)$ into blocks of K points [2]. That is

$$\begin{aligned} \widetilde{x}_m(r) &= \sum_{l=-\infty}^{\infty} \widetilde{y}_m(r+lK) \\ &= \sum_{l=-\infty}^{\infty} h(-r-lK)x(r+lK+mD), \qquad r = 0,1\cdots K-1 \end{aligned} \tag{8}$$

So

$$\widetilde{X}_k(m) = \sum_{r=0}^{K-1} \widetilde{x}_m(r)W_K^{-kr} \tag{9}$$

According to Eq.5~Eq.9, calculation of $X_k(m)$ is summarized as follows



Above procedure is another way to calculate $X_k(m)$ in Eq.1, corresponding structure is called WOLA structure for channelizer, as shown Fig.3. Here assume $L = 4K$. L is filter order and length of input register. The detail steps are:

1) Input D points of $x(n)$, it is determined by Eq.5 and Eq.6.

2) Weight $x(n)$ with filter $h(-r)$, when $h(r)$ is symmetrical, $h(r) = h(-r)$.

3) Overlap-Add. Divide weighted sequences into blocks

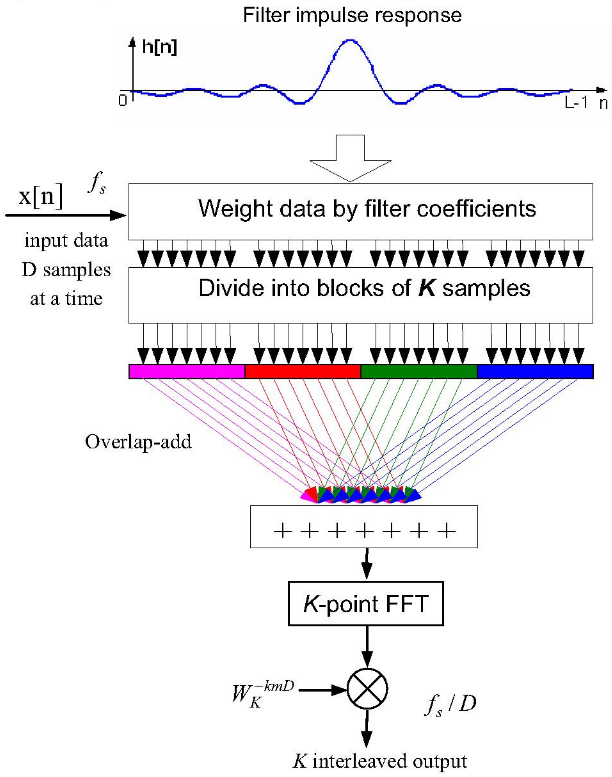


Fig.3 WOLA channelizer

of K samples and add them together as Eq.8.

4)Calculate $\widetilde{X}_k(m)$ with FFT algorithm as Eq.9.

5)Multiply W_K^{-kmD} to get $X_k(m)$, as shown in Eq.4.

In Fig 3, Input D samples of $x(n)$ at a time will obtain K point's parallel outputs, which are outputs in K channels. Forms above analysis, the excellences of WOLA channelizer are as follows:

1) Input rate is f_s, but calculation is for D samples, so the working speed is f_s / D .

2) Comparing conventional channelizer in Fig.1, just one filter is needed. The filter is used to weight rather than compute convolution.

3) DFT is calculated with FFT algorithm.

4) Decimation factor D is independent with channel number K.

So WOLA is a flexible and high efficient filterbank to realize channelized receivers. When $D = K$, Eq.3 and Eq.5 are equal with Eq.1 mathematically. If $D \neq K$, PDFT isn't suitable while WOLA isn't influenced. So WOLA structure is a generational form of PDFT. WOLA filterbank also can be used in STFT with the delay parameter is integral times of D. If D=1, WOLA is identical with conventional STFT structures.

IV. DESIGN EXAMPLE

To prove the efficiency of proposed structure, we design a 16 channels receiver. Input is composed by two complex signals. One is complex exponential signals. Its frequency is 60MHz. The other is complex linear frequency modulated (LFM) signals. Its center frequency is150MHz and bandwidth is 20MHz. Assume sampling frequency f_s is 800MHz. The whole frequency band $-f_s / 2 \sim f_s / 2$ is separated into 16 channels. Bandwidth in each channel is 50MHz. Channel splitting and spectrums of input signals are shown in Fig.4. The sub-channels are marked as -8~7. WOLA filterbank is used to realize demodulation, filtering, and decimation. Filter order L= 128, decimation factor D=8. Points of FFT and channel number are 16.Input sequences are 2048 points. According to analysis in section 3, outputs of each channel are 256 points and rate is 100MHz. Spectrums of channel 1, 2 and 3 are shown in Fig.5.

Demodulation will transfer intermediate frequency to baseband, so frequency of channel 1 is 10MHz while channel 3 centered at zero frequency. Comparing the results in Fig.5 with inputs in Fig.4, they are consistent with proposed structure.

V. CONCLUTIONS

WOLA filterbank is applied to channelized receiver in this paper. We deduce the WOLA structure from results of lowpass filterbank and prove it is as high efficient as famous PDFT structure. WOLA structure is a generalized form of PDFT structure. They are mathematically equal. The WOLA channelizer is flexible, low computation and hardware efficient. It is suitable for communication, radar, and GPS receivers.

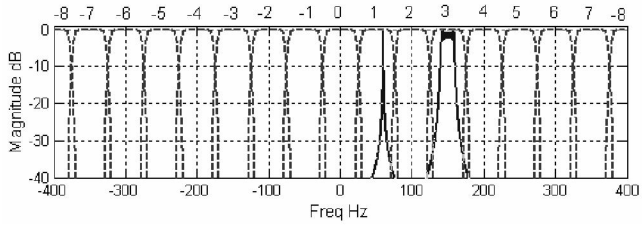


Fig.4 Channel spitting and spectrums of input signals

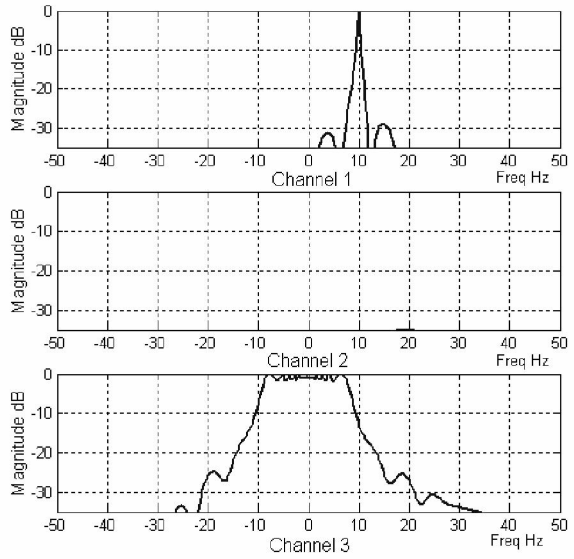


Fig.5 Spectrums of output signals

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