An Implementation of Digital Crossover Network by using Perfect Linear Phase IIR Filters

C.Kanna, D. Sookcharoenphol and K. Janjitrapongvej.
Information Dept., Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang
Chalongkrung Road, Ladkrabang Bangkok THAILAND
Email: ksdolcha@kmitl.ac.th

Abstract

In this paper, the implementation technique of digital crossover network using perfect linear phase IIR filters is presented. This system has various advantages which can not be obtained from analog crossover network such as linear phase response, flat group delay and sharp cut-off at low-order over audio frequency band. The simulation results show that the group delay response is maximally flat and twice more attenuation in stop-band than the prototype elliptic IIR filter at all desired frequency.

1. Introduction

Classical design of two-way digital crossover networks consist of low-pass filter and high-pass filter to split the audio signal into low-pass signal and high-pass signal, and each feeding to a separated loudspeaker. However, the amplitude, phase and group delay distortions can not be eliminated and it is difficult to achieve perfect reproduction [1] and [2]. We can derived the odd-order digital low-pass filter using the Bilinear transform and it can be implemented as a sum of two all-pass filters [3]. Two stable all-pass filters (APF) which transfers function pairs that is satisfied to all-pass complementary property was proposed by Regalia and et al [4]. It is well known that this two stable APF have less sensitivity and circuit complexity than the classical design. An implementation of the all-pass complementary filter pairs as the sum and difference of all pass functions is shown in fig1

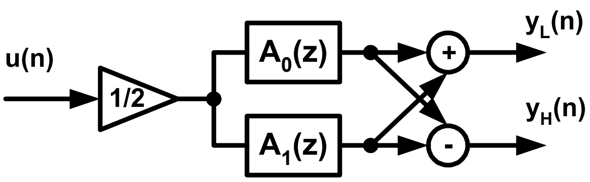

Fig. 1 Two-parallel APF is implementing of two-way crossover network.

The implementation of two-way digital crossover can be derived by using two-parallel IIR all-pass function as [5]. We can write in the expression of low-pass filter and high-pass filter. Transfer function is given as follows

$$H_{LPF}(z) = \frac{1}{2}\left[A_0(z) + A_1(z)\right] \quad (1)$$

$$H_{HPF}(z) = \frac{1}{2}\left[A_0(z) - A_1(z)\right] \quad (2)$$

where $A_0(z)$ and $A_1(z)$ are stable APF

2. Linear Phase IIR Filter

An implementation of real-time linear phase IIR low-pass filters was proposed by Powell and Chau [6]. Hence, that system is possible to implementation of two-band digital crossover networks. However Group delay distortion, linear-time variant system and computational complexity are complicated.

Fig. 2 shows an implementation of two-way digital crossover networks using Linear Phase IIR Filter with complementary filter pairs. In the system, input sequence is time reversed on block by block using LIFO (last-in first-out) and then sectioned-convoled with $H_{LPF}(z)$ and $H_{HPF}(z)$ to realize a real-time recursive implementation of the non-causal transfer function after time reversed by LIFO again, the sequence passes through causal transfer function H(z) to obtain a linear phase IIR filters

2.1. Perfect Linear Phase IIR Filters

We can derive almost perfect reproduction of audio signal from two-way digital crossover network by using perfect linear phase IIR filters [7]. This system can improve both group delay distortion and linear-time variance system to Linear-time invariant (LTI) of Powell and Chau system by truncating infinite impulse response method [8].

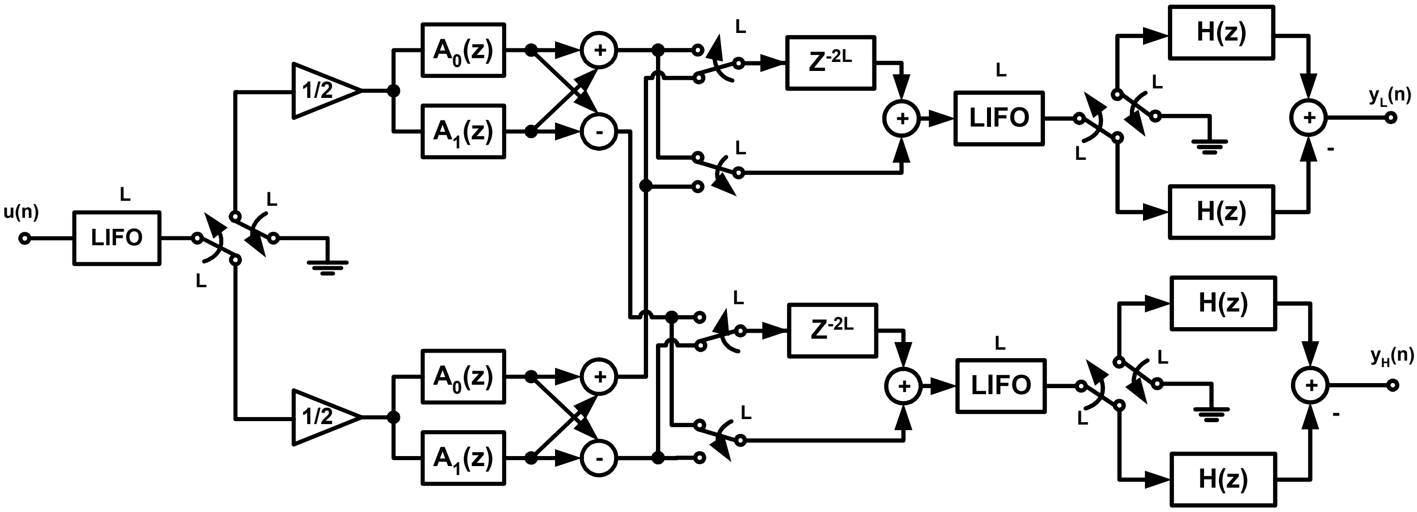

Fig. 2 Implementation of Linear Phase IIR Filter with complementary filter pairs

This method truncates the finite impulse response of linear phase IIR filter to finite length by using IIR filter direct form II to approximate a residue impulse response. Then subtract from the IIR filter with the transfer function H(z) and the output of the truncated filter is a finite impulse response.

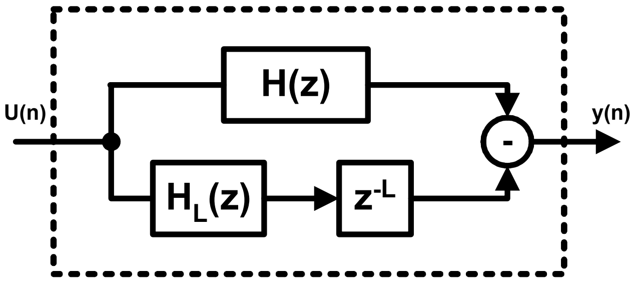

Fig. 3 Truncated IIR Filters

Impulse response of $H_L(z)$ with L sample delay can be defined as

$$h_L(n-L) = \begin{cases} h(n) & n \geq L \\ 0 & n \leq L \end{cases} \tag{3}$$

where h(n) is an impulse response of IIR filter H(z), L is sample length. We consider the direct form II IIR filter (K-order) in rational transfer function as follow

$$H(z) = \frac{a_0 + a_1 Z^{-1} + a_2 Z^{-2} + \ldots + a_K Z^{-K}}{1 - b_1 Z^{-1} - b_2 Z^{-2} - \ldots - b_K Z^{-K}} \tag{4}$$

where $a_1, a_2, \ldots, a_K$ and $b_1, b_2, \ldots, b_K$ are real number coefficients for efficient computational of $H_1(z)$, a minimum order in this case is second order. Therefore, we can rewritten Eq.(4) to the second order transfer function and applied to two-band of digital crossover networks is as follows

Truncated IIR filter for low-pass filter

$$H_{L-LPF}(z) = \frac{c_{L0} + c_{L1} Z^{-1} + c_{L2} Z^{-2}}{1 - b_{L1} Z^{-1} - b_{L2} Z^{-2}} \tag{5}$$

Truncated IIR filter for high-pass filter

$$H_{L-HPF}(z) = \frac{c_{H0} + c_{H1} Z^{-1} + c_{H2} Z^{-2}}{1 - b_{H1} Z^{-1} - b_{H2} Z^{-2}} \tag{6}$$

In Fig. 4 shows an implementation of two-way digital crossover networks by using perfect linear phase IIR filters and the output signal of low-pass filter is $y_L(n)$ and the output signal from high-pass filter is $y_h(n)$.

3. Simulations

An elliptic H(z) is designed according to the following specification

- Normalized frequency pass band $\omega_n = 0.5$
- Pass band ripple $\delta_p = 0.5dB$
- Stop band ripple $\delta_s = 20dB$

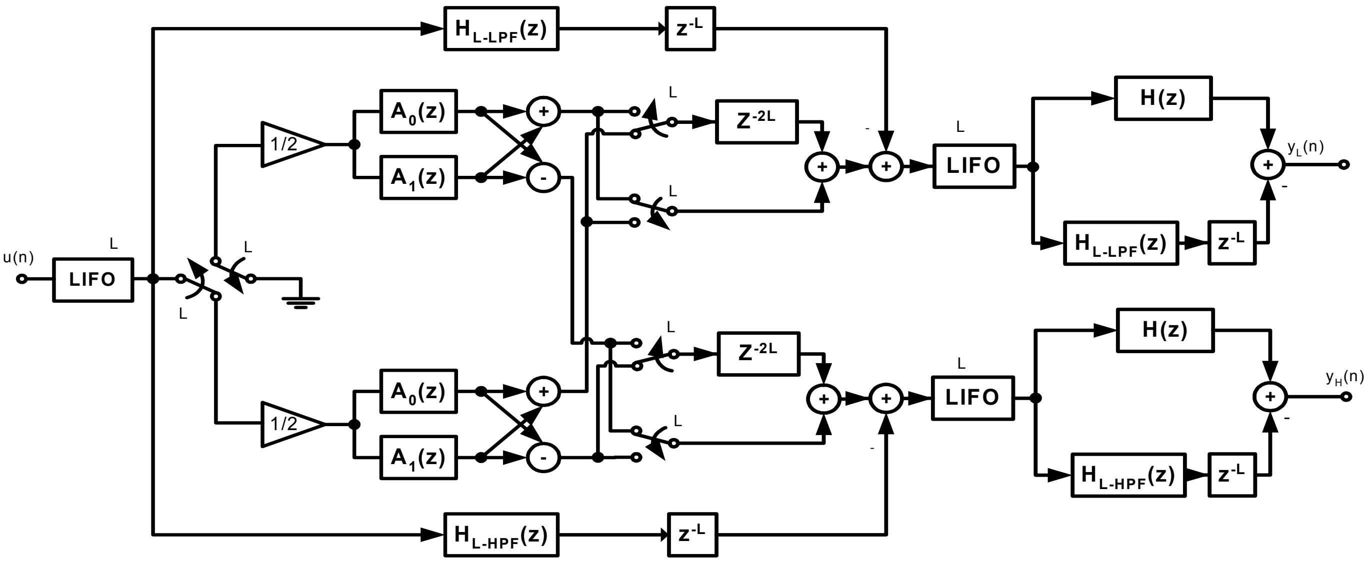

Fig. 4 Implementation of power complementary Perfect linear phase IIR filter by using over-lap add convolution.

Then, we can decompose the transfer function H(z) into two-stable APF as follows

$$A_0(z) = \frac{-0.7314 + Z^{-1}}{1 - 0.7314Z^{-1}} \qquad (7)$$

$$A_1(z) = \frac{-0.6679 + 0.1151Z^{-1} + Z^{-2}}{1 + 0.1151Z^{-1} + 0.6679Z^{-2}} \qquad (8)$$

Then, we can substitution $A_0(z)$ and $A_1(z)$ into Eq. (1), yields

$$H_{LPF}(z) = \frac{0.2759 + 0.5121Z^{-1} + 0.5121Z^{-2} + 0.2759Z^{-3}}{1 - 0.0010Z^{-1} + 0.6546Z^{-2} - 0.0775Z^{-3}} \qquad (9)$$

Similarly, we substitute $A_0(z)$ and $A_1(z)$ into Eq. (2), yields

$$H_{HPF}(z) = \frac{0.3920 - 0.4745Z^{-1} + 0.4745Z^{-2} - 0.3920Z^{-3}}{1 - 0.0010Z^{-1} + 0.6546Z^{-2} - 0.0775Z^{-3}} \qquad (10)$$

Generally, the residual impulse response is governed domainly by the poles of the transfer function nearest to the unit circle in Z-plane. Therefore, H_{L-LPF} and H_{L-HPF} can be approximated by 2nd - order function $\tilde{H}_L(z)$ using pair of complex conjugate poles nearest to the unit circle. Denoting the conjugate pole as z_1 and $\bar{z}_1$, the numerator of $\tilde{H}_L(z)$ are determined by equating the first three impulse resonse samples of $\tilde{H}_L(z)$ with the residual response

Transfer function of $H_{L-LPF}(z)$ and $H_{L-HPF}(z)$ can be written in rational polynomial in Z-domain. It minimum order is second order(n=2) given as follows

$$H_{L-LPF}(z) = \frac{-0.00034986 - 0.00262908Z^{-1} - 0.00010842Z^{-2}}{1 + 0.11514478Z^{-1} + 0.66791907Z^{-2}} \qquad (11)$$

$$H_{L-HPF}(z) = \frac{0.00034986 + 0.00262908Z^{-1} + 0.00030363Z^{-2}}{1 + 0.11514478Z^{-1} + 0.66791907Z^{-2}} \qquad (12)$$

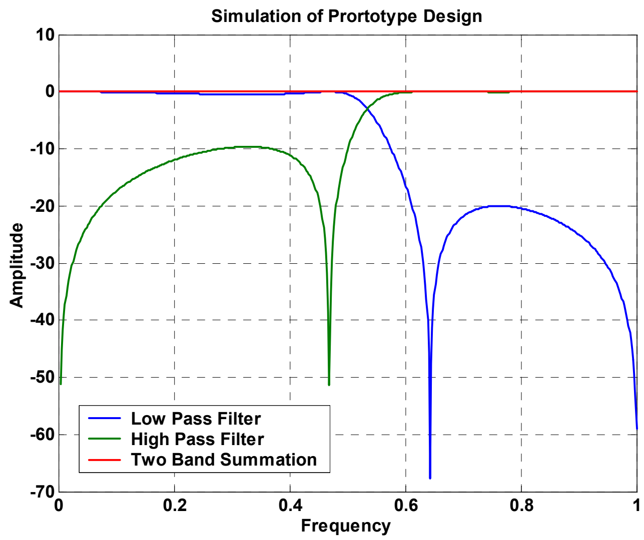

Fig. 5 Summation of complementary system magnitude response of prototype third-order elliptic IIR filter.

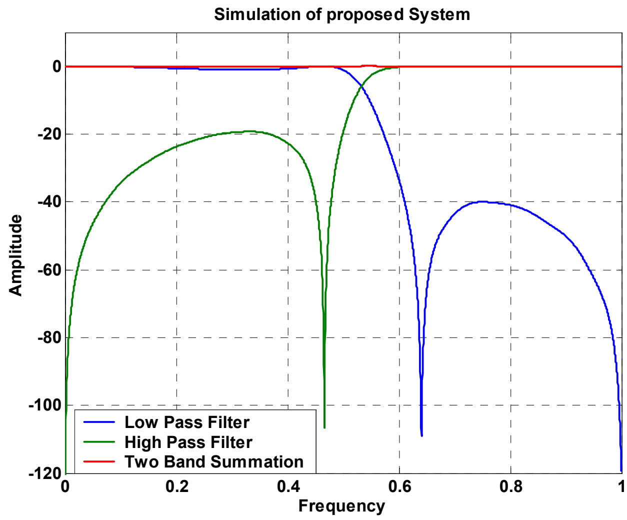

Fig. 6 Summation of complementary system magnitude response is flat response of proposed

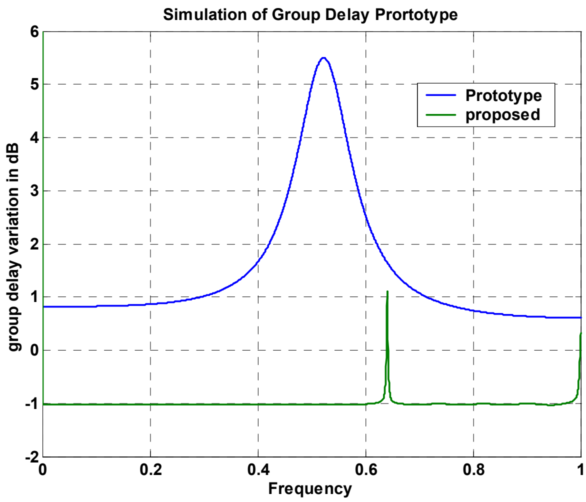

Fig. 7 Upper trace shown the group delay variation of prototype filter and lower trace shown the group delay of proposed system

4. Conclusion.

An implementation of two-band digital crossover networks by using perfect linear phase IIR filters is presented. The simulation results of proposed system show that group delay variation is flat as show in fig 7. magnitude response is twice attenuation in stop band in fig 6 than does the prototype filter in fig 5 their impulse response of both low-pass signal and high-pass signal are symmetry at the peak amplitude.

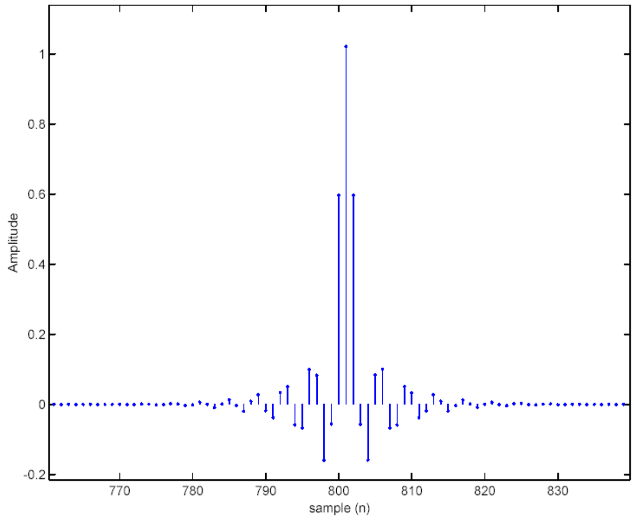

Fig. 8 Impulse response of propose low-pass filter $y_L(n)$

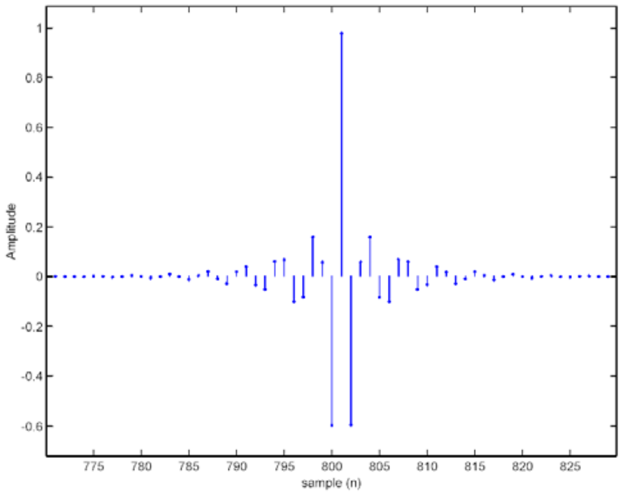

Fig. 9 Impulse response of propose high-pass filter $y_H(n)$

5. Reference.

[1] P.Reviriego, Jose Parera and R. Garcia, "Linear-Phase Crossover Design Using Digital IIR Filters", J. Audio Eng.Soc.,Vol. 46, No. 5, pp 406-410, May. 1998.

[2] Rhonda Wilson, Glyn Adams and Jonathan scott, "Applicacition of Digital Filter to Loundspeaker Crossover Networks", ", J. Audio Eng.Soc.,Vol. 37, No. 6, pp 455-463, June. 1998.

[3] Tapio Saramaki, "On the Design of Digital Filters as a Sum of Two All-Pass Filters", IEEE Trans., Vol. CAS-32, No. 11, pp. 1191-1193, Nov. 1985.

[4] Phillip A. Regalia, Sanjit K. Mitra and P. P. Vaidyanathan, "The Digital All-Pass Filter : A V ersatile Signal Processing Building Block", Proc. IEEE, Vol. 76, No. 1, Jan. 1988.

[5] P. P. Vaidyanathan A. Sanjit K. Mitra Yrjo Neuvo, “A New Approach to the Realization of Low-Sensivity IIR Digital Filters”, IEEE Trans. ASSP., Vol. 34, No.2, pp.350-361, Apar. 1986.

[6] Scott R. Powell and Paul M. Chaul ,”A Technique for Realizing Linear Phase IIR Filter”, IEEE Trans, Signal Processing, Vol.39, No.11, PP. 2425-2435, Nov.1991.

[7] D. Sookcharoenphol and et al. , “An anaysis of linear phase IIR filters and a condition for perfect linear phase”, ICEP 2003, pp. 144-147, Jan., 2003.