Simulation of Frequency Response Masking Approach for FIR Filter design

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Abstract: - Recently the attention has to a large extent been paid to the problem of designing perfect reconstruction (PR) filter banks. However, filter banks are most often used in applications where small errors are inevitable and allowed. Imposing PR on a filter bank is then an unnecessarily severe restriction which may lead to a higher arithmetic complexity than is actually required to meet the specification at hand. Much of the efforts have been done to design near PR filter banks using different techniques. One such techniques is by decomposing the overall transfer function of filter into its poly-phase form, all filtering in the interpolators and decimators can be performed at the lowest of the two sampling rates involved resulting in a low overall complexity. Frequency Response Masking (FRM) Approach developed to design FIR filter structures for interpolation and decimation has drawn much attention in the filter designing field. In this paper, simulated results for FRM approach for the designing of FIR filter is presented in a step-by-step fashion in order to elaborate the process. Finally a graphical comparison is made between FIR filter designed using FRM approach and traditional approach.

Key-Words: - Perfect Reconstruction (PR) filters, frequency-response masking (FRM), near perfect reconstruction (NPR) filter bank, FIR filters, Linear Phase filters.

1 Introduction

There exist many applications in modern signal processing where it is advantageous to separate a signal into different frequency ranges called sub-bands. And this is achieved by filters. Goals in filter design are firstly, to achieve good sub-band frequency separation (i.e., good "frequency selectivity") and secondly, to achieve good reconstruction when the sub-band processing is lossless. The first goal is driven by the assumption that the sub-band processing works best when it is given access to cleanly separated sub-band signals, while the second goal is motivated by the idea that the sub-band filtering should not limit the reconstruction performance when the sub-band processing (e.g., the coding/decoding is lossless or nearly lossless.

Finite-impulse response (FIR) filters are often preferred to infinite-length impulse response (IIR) filters for several reasons [1], one main reason being that they can be made to have an exact linear phase. However, the order and complexity of FIR filters are very high when the transition bandwidth is narrow [2-4]. This paper deals with these same kinds of filters and which are used with Interpolation and decimation which are based on the frequency-response masking (FRM) approach. By using the FRM approach it is possible to obtain FIR filters requiring few multipliers even when the transition band is narrow. Further, by decomposing the overall transfer function into its poly-phase form, all filtering in the proposed interpolators and decimators can be performed at the lowest of the two sampling rates involved resulting in a low overall complexity. In this paper, we are concerned with the simulation of new filter designing approach called as Frequency Response Masking (FRM) Approach. We would first explain the interpolation and decimation by a factor of two which is the simplest case in section 2, then my factor of M in section 3 and would explain the FRM approach in section 5 and would present the results of the simulation in section 6 using an example.

2. Interpolation and decimation two.

By decomposing the overall transfer function of filter into its poly-phase form, all filtering in the interpolators and decimators can be performed at the lowest of the two sampling rates involved resulting in a low overall complexity. The poly-phase representation is in case interpolation and decimation by factor of two is given by

\[ H(z) = H_0(z^2) + z^{-1}H_1(z^2) \]  

(1)

Where, \( H_0 \) and \( H_1 \) are referred to as the polyphase components. The corresponding polyphase interpolator and decimator structures are shown in Figs. 1 and 2, respectively. The filtering is performed at the lowest sampling rate which results in a low arithmetic complexity (i.e., few
multiplications and additions per sample are required). Interpolators and decimators for sampling rate conversion by a factor of two are also useful in cases where the conversion factor is larger than two since it often is advantageous to do the overall conversion in several steps, where in each step a conversion by a small factor is performed.

Figure 1: Polyphase interpolator structure

Figure 2: Polyphase decimator structure

3. Interpolation and decimation by M.
This approach is based on same aspect of reducing the complexity as previously explained in section 2, and is in fact extension of the interpolation and decimation by factor of two. The poly-phase representation is in this case given by

\[ H(z) = \sum_{m=0}^{M-1} z^{-m} H_m(z^M) \]

Where, \( H_m(z) \) are referred to as the poly-phase components. The corresponding poly-phase interpolator and decimator structures are shown in Figs 3 and 4, respectively. The filtering is performed at the lowest sampling rate which results in a low arithmetic complexity (i.e., few multiplications and additions per sample are required).

4. FIR Filters
In many applications, it is desired to use FIR filters; one main reason is that they can be made to have a linear phase response. However, the order and complexity of FIR filters are very high when the transition band is narrow [4]–[6]. So lot of research has been underway to develop/design high performance filters.

5. Frequency-Response masking
In the frequency-response masking approach [7][8], the transfer function of the overall filter is expressed as

\[ H(z) = G(z^L)F_0(z) + G_c(z^L)F_1(z) \]

Where \( L \) is some positive integer. The filters \( G(z) \) and \( G_c(z) \) work as a model filter and a complementary model filter, respectively. The filters \( F_0(z) \) and \( F_1(z) \) work as masking filters which extract one or several passbands of the periodic model filter \( G(z^L) \) and periodic complementary model filter \( G_c(z^L) \). In the lowpass case, typical magnitude responses for the model, masking, and overall filters are as shown in Fig. 5 where \( k \) is a positive integer. The transition band of \( H(z) \) can be selected to be provided by one of the transition bands of either \( G(z^L) \) or \( G_c(z^L) \). We refer to these
two different cases as Case 1 and Case 2, respectively. And are shown in figure 5 and figure 6 respectively.

Further, we let $\omega_T$, $\delta_c$, and $\delta_s$ denote the passband edge, stopband edge, passband ripple, and stopband ripple, respectively, for the overall filter $H(z)$. For the model and masking filters $G(z)$, $G_c(z)$, $F_0(z)$, and $F_1(z)$, additional superscripts $(G)$, $(G_c)$, $(F_0)$, and $(F_1)$, respectively, are included in the corresponding ripples and edges.

The complete system of frequency response masking approach is shown in the figure 7

In [9] a class of $M$-band linear-phase FIR filters synthesized using the FRM approach has been introduced, which makes it possible to obtain $M$-band FIR filters requiring few arithmetic operations even when the transition band is narrow. An approach for synthesizing two-channel maximally decimated FIR filter banks utilizing the FRM technique is proposed in [10], which compared to conventional quadrature-mirror filter (QMF) banks has lower significantly the overall arithmetic complexity at the expense of a somewhat increased overall filter bank delay in applications demanding narrow transition bands.

6. Design example

We tested the FRM approach using several examples one of which is demonstrated using figures (8-15) obtained using MATLAB. Fig 8 and 9 shows model filter and complementary model filter respectively and figure 10 and figure 11 shows their periodic counter. Figure 12 and figure 13 shows masking filters $F_0(z)$ and $F_1(z)$ respectively. Finally, the total overall filter achieved using FRM approach is shown in the figure 14. For comparison purpose, frequency response and phase response of traditional FIR filter is shown in the figure 15.

7. Conclusion

This paper has presented simulation of the FIR filter designing using FRM Approach. This approach help to design FIR filters for which the order will be higher, since it is not possible to beat the optimum filters in this respect. However, the benefit of FRM FIR filters is that the number of arithmetic operations required can be substantially smaller, because of the zero-valued impulse response values of the periodic model filter and at the same time a narrow transition band. FRM has been simulated in MATLAB and results have helped to elaborate FRM approach for FIR filter designing in a step by step fashion. Finally a graphical comparison has been shown between Filters designed using FRM approach and the traditional approach.
Figures 8-11: Graphs illustrating various model filters and their complementary models.
Figure 12: $F_0(z)$ a masking filter

Figure 13: $F_1(z)$ a masking filter

Figure 14: Total filter $H(z)$

Figure 15: Traditional FIR filter of same order
REFERENCES


