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. To reduce the complexity one should therefore use near-PR filter banks. In this paper, essential features of the recently introduced frequency-response masking (FRM) approach as a means of generating narrow transition band linear-phase FIR filters with a low arithmetic complexity are explained and demonstrated using simulation. By decomposing the overall transfer function into its polyphase 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. Simulated results show the difference between the FIR filter designed using FRM approach and traditional FIR filter of same order. The ripple contents of the pass-band of the filter designed using FRM approach are more as compare to the traditional one.

Key-Words: - Perfect Reconstruction (PR) filters, frequency-response masking (FRM),FIR filters, Interpolation and decimation.

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,** which is his is achieved by filters. One goal in filter design is to have good sub-band frequency separation (i.e., good "frequency selectivity"). Second is to have 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 nealy 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 same FIR filters, which are used with Interpolation and decimation. FIR filter design is of major problem in the field of signal and image processing. This paper would explain the simulated results for the designing of FIR filters, 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 polyphase 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 structures for interpolation and decimation by integer factors two. We would first explain the interpolation and decimation by a factor of two in section 2, by factor of M in section 3 and FRM approach in section 4. Finally, simulated FIR filter design results are explained in section 5.

2. Interpolation and decimation by a factor of two.

This approach, which is recently proposed in [7] by Håkan Johansson, describes interpolation and decimation by a factor of two. The polyphase representation is in this case given by

$$H(z) = H_0(z^2) + z^{-1}H_1(z^2) \quad (1)$$

Where, H_0 (z) and H_1 (z) 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. In many applications, it is desired to use FIR filters; one main reason being that they can be made to have an exact linear phase.

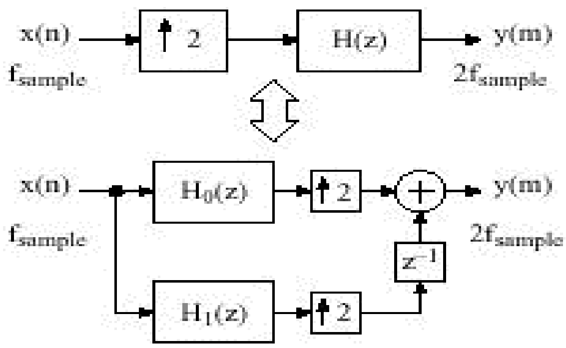

Figure 1: Polyphase interpolator structure

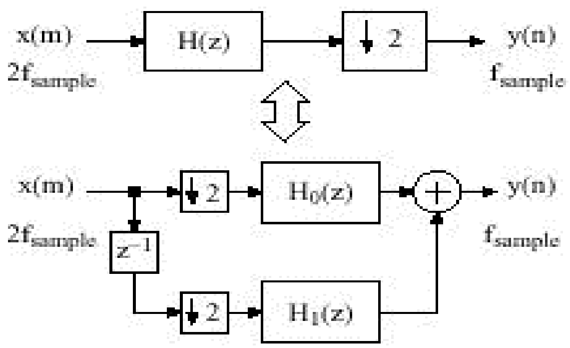

Figure 2:Polyphase decimator structure

3. Interpolation and decimation by a factor of M.

This approach, which is proposed by Håkan Johansson in [9], is based on Interpolation and decimation by a factor of two (explained in section 2). The polyphase 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 polyphase components. The corresponding polyphase 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).

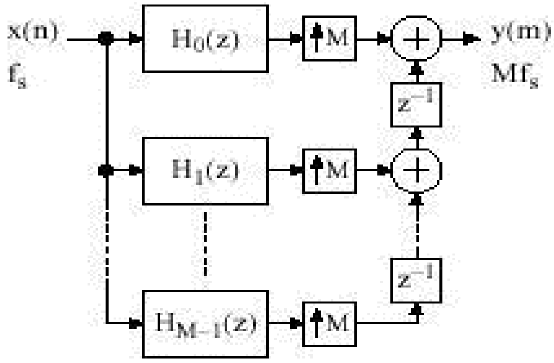

Figure 3 : Polyphase interpolator structure

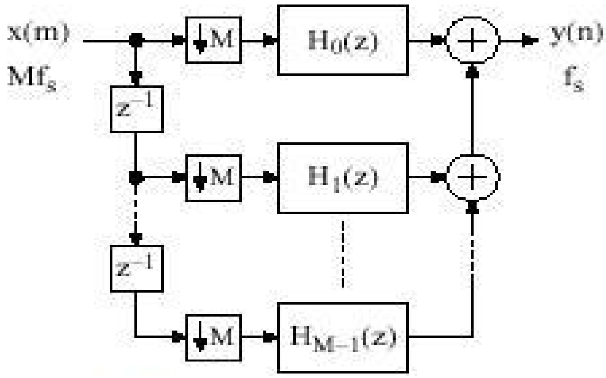

Figure 4: Polyphase decimator structure

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].

4. Frequency-Response masking Approach

In the frequency-response masking approach [9][10], 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 *Gc(*z) work as a *model filter* and a *complementary model filte*r, 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 $\omega_c T$, $\omega_s T$, δ_c ,and δ_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.

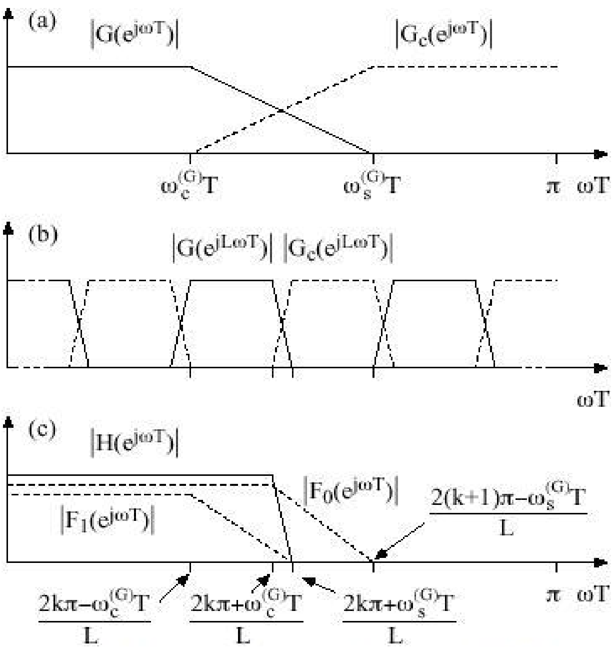

Figure 5: Frequency Response Masking (Case 1)

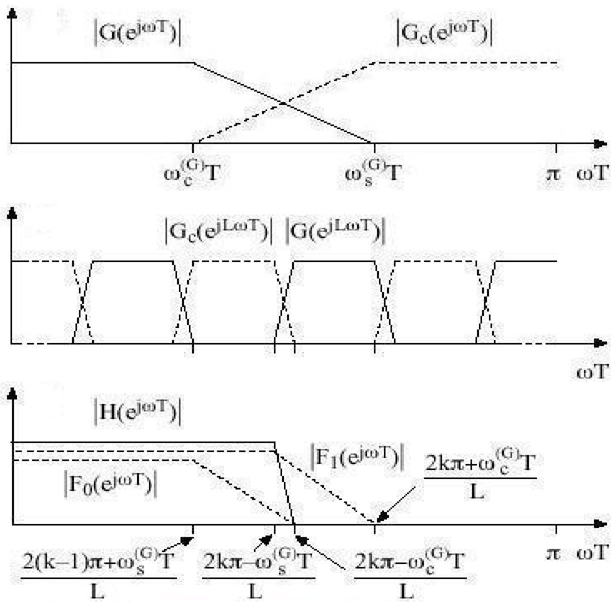

Figure 6: Frequency Response Masking (Case 2)

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

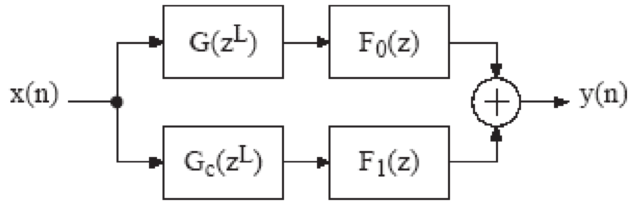

Figure 7: Structure used in the FRM approach

In [8] it has been a class of M^{th}-band linear-phase FIR filters synthesized using the FRM approach has been introduced, which makes it possible to obtain M^{th}-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.

5. 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.

6. Conclusion

This paper has discussed new FRM FIR filter structures for interpolation and decimation by a factor of two and then by an integer factor. The order will be higher for the FRM filters, 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 approach is demonstrated using simulation in MATLAB and results are presented. Simulated results have clearly shown the difference between the FIR filter designed using FRM approach and traditional FIR filter of same order, which being the increased ripple contents of the pass-band of the filter designed using FRM approach.

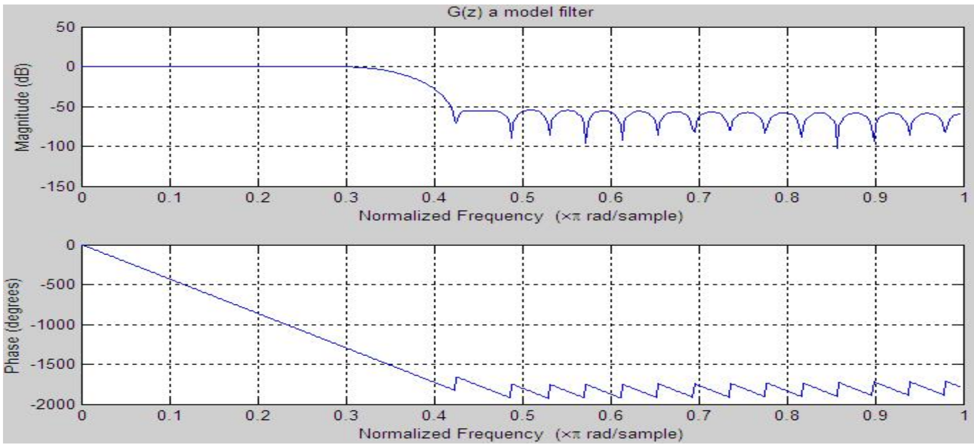

Figure 8: G(z) a model filter

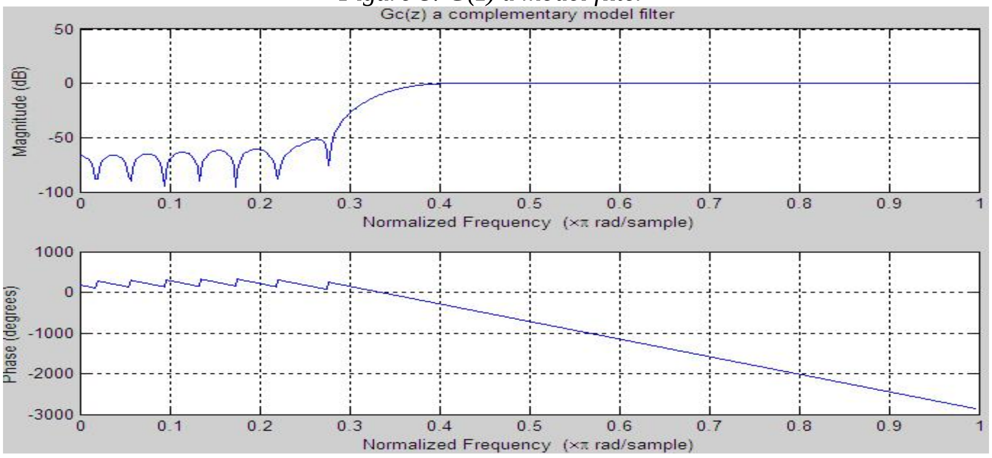

Figure 9: $G_c(z)$ a complementary model filter

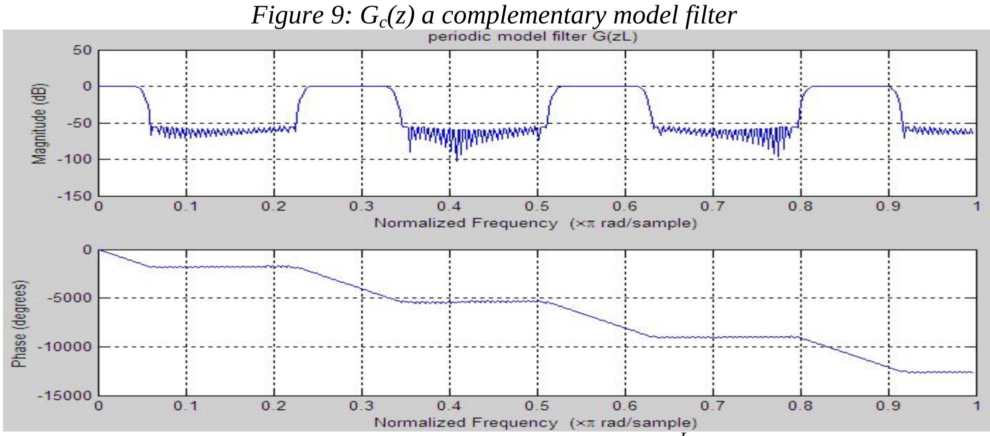

Figure 10: Periodic model filter $G(z^L)$

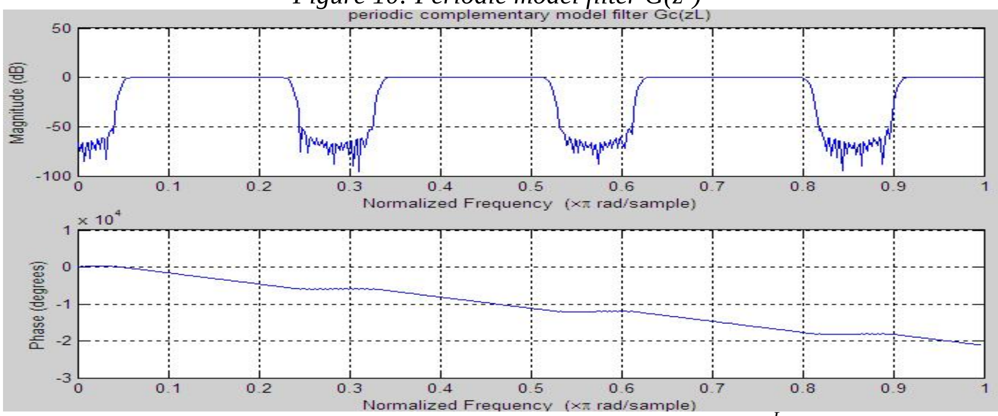

Figure 11: Periodic complementary model filter $G_c(z^L)$

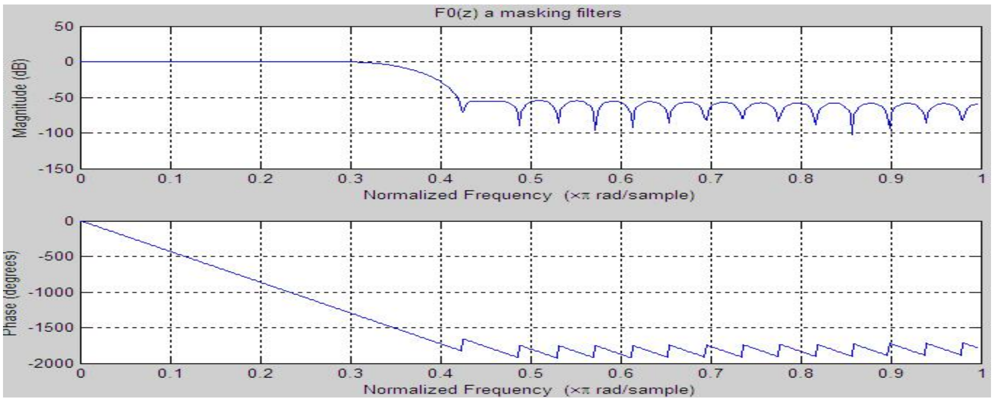

Figure 12: $F_0(z)$ a masking filter

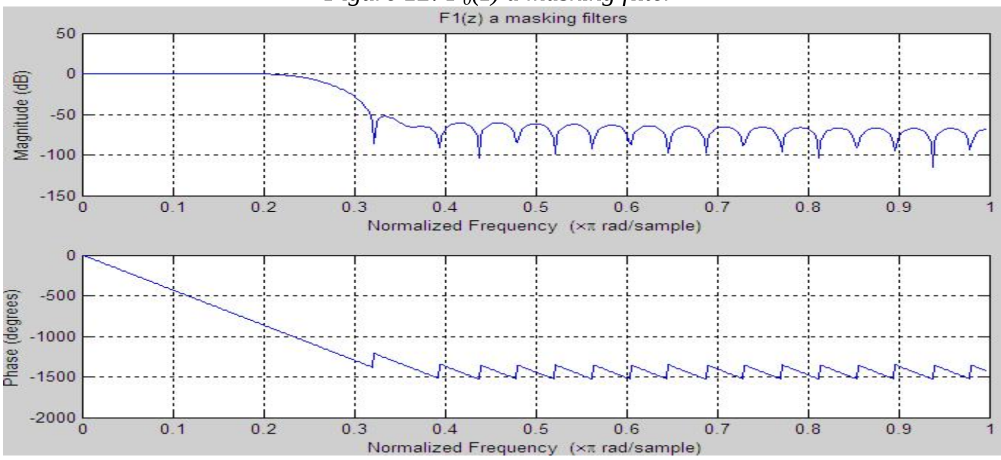

Figure 13: $F_1(z)$ a masking filter

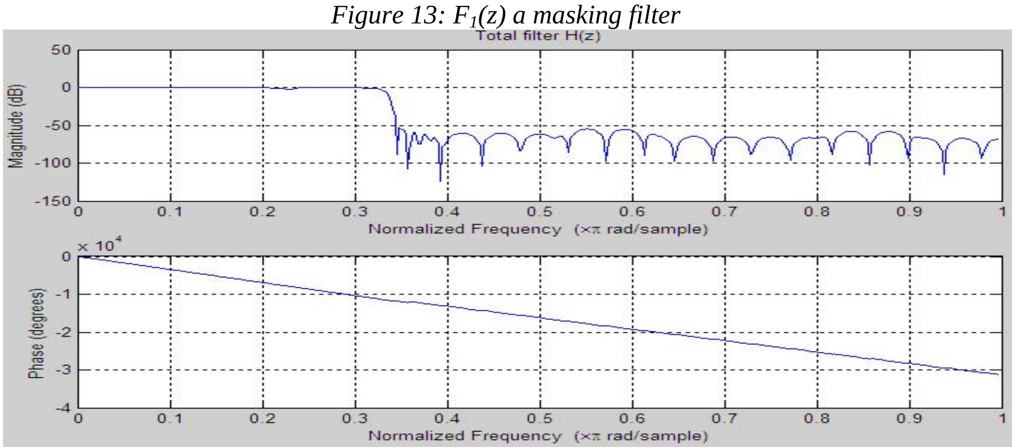

Figure 14: Total filter H(z)

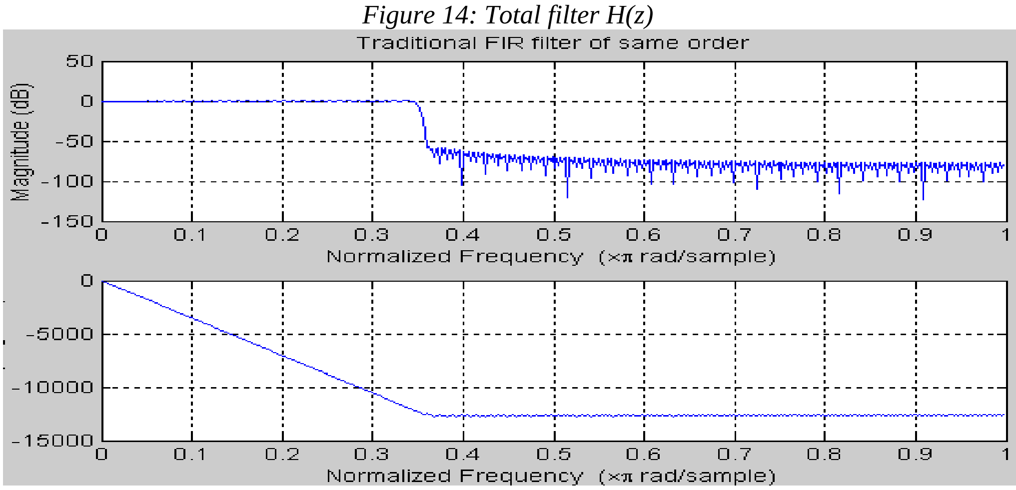

Figure 15: Traditional FIR filter of same order

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