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Design of FIR Filter using Filter Response Masking Technique

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Abstract- In this paper author is trying to implement Frequency response masking (FRM) technique. In this technique the frequency responses of complementary pair filters are masked by the frequency responses of two appropriate masking filters. These masking filters can be designed with method of FIR filter designing; window technique is used here for the same purpose.

Keywords: FRM

I. Introduction

Frequency response masking technique is first introduced by *Yong ching Lim* in 1986 [1]. It was a simplest implementation technique where M delay introduced to linear phase low-pass filter resultant better steeper transition from pass-band to stop-band. FRM technique is further optimized in one and two dimensional FIR filter designing by *Y C Lim* and *Yong Lian* in 1993 [2][3].

This paper is organized as section I is about the introduction and history of FRM technique and basic aspects of it. Section II, III and IV are about implementation of FRM technique in stage-I, stage-II and stage-III. Final conclusion is made in section-V.

II. FRM Stage-I

Initially two linear phase Finite impulse response filters H_a and H_c is considered which complement with each other. Frequency response of the filters H_a is defined as

$$H_a(e^{i\omega}) = e^{-j((N-1)/2)\omega} R(\omega) \qquad (1)$$

Where N is length of the filter and $R(\omega)$ is a trigonometry function given below in equation (2) and fig. (1):

$$R(\omega) = \begin{matrix} 1 & from\ 0 < \omega < \theta \\ 0 & from\ \phi < \omega < \pi \\ \frac{\omega-\phi}{\theta-\phi} & from\ \theta < \omega < \phi \end{matrix} \qquad (2)$$

The frequency response of complementary filter H_c is

$$H_c(e^{i\omega}) = e^{-j((N-1)/2)\omega}\{1 - R(\omega)\} \qquad (3)$$

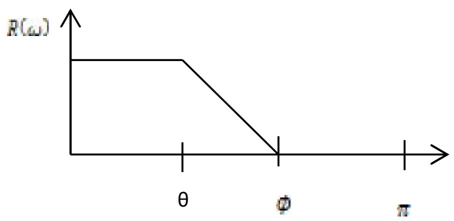

Figure 1 Trigonometry function $R(\omega)$

Or it can be also represented as

$$H_c(e^{i\omega}) = e^{-j((N-1)/2)\omega} - H_a(e^{i\omega}) \qquad (4)$$

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Which means H_c can be calculated by subtracting H_a with delay function shown in fig. (2); Where $X(e^{i\omega})$ will be considered as any input function applied into it and Consider $\mathbf{H_a}$ low pass FIR filter designed using window technique having cut-off frequency θ. Because of the complementary pair of $H_a(e^{i\omega})$ and $H_c(e^{i\omega})$ it will be represented as

$$H_a(e^{i\omega}) + H_c(e^{i\omega}) = 1 \qquad (5)$$

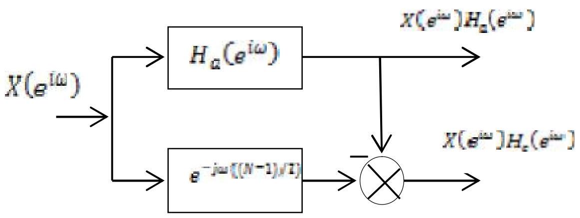

Figure 2 $H_a(e^{iw})$ and $H_c(e^{iw})$ filter with delay function

Now, after analyzing the basic structure of the FIR filters; block diagram of first stage of implementation of FRM technique is shown in fig. (3).

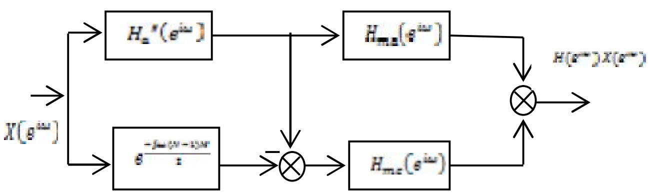

Figure 3 Structure of frequency response masking technique

Two filters $\mathbf{H'_a}$ and $\mathbf{H'_c}$ are formed by including delay of Min frequency response of given filters $\mathbf{H_a}$and $\mathbf{H_c}$. Therefore $H'_a(e^{i\omega}) = H_a(e^{iM\omega})$ and $H'_c(e^{i\omega}) = H_c(e^{iM\omega})$. Two masking filters $H_{ma}(e^{i\omega})$ and $H_{mc}(e^{i\omega})$ are also considered to mask frequency response of the given filters $H'_a(e^{i\omega})$ and $H'_c(e^{i\omega})$. Implementation of masking filter will be done by window technique of FIR filter design. Here hamming window is used for implementation of masking filter. The complete structure is as shown in flow chart (Appendix A).

The generated response of first stage filter and analysis synthesis side is as shown in figure 4 and figure 5 respectively.

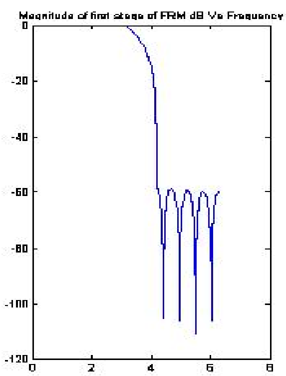

Figure4 first stage FRM output (dB)

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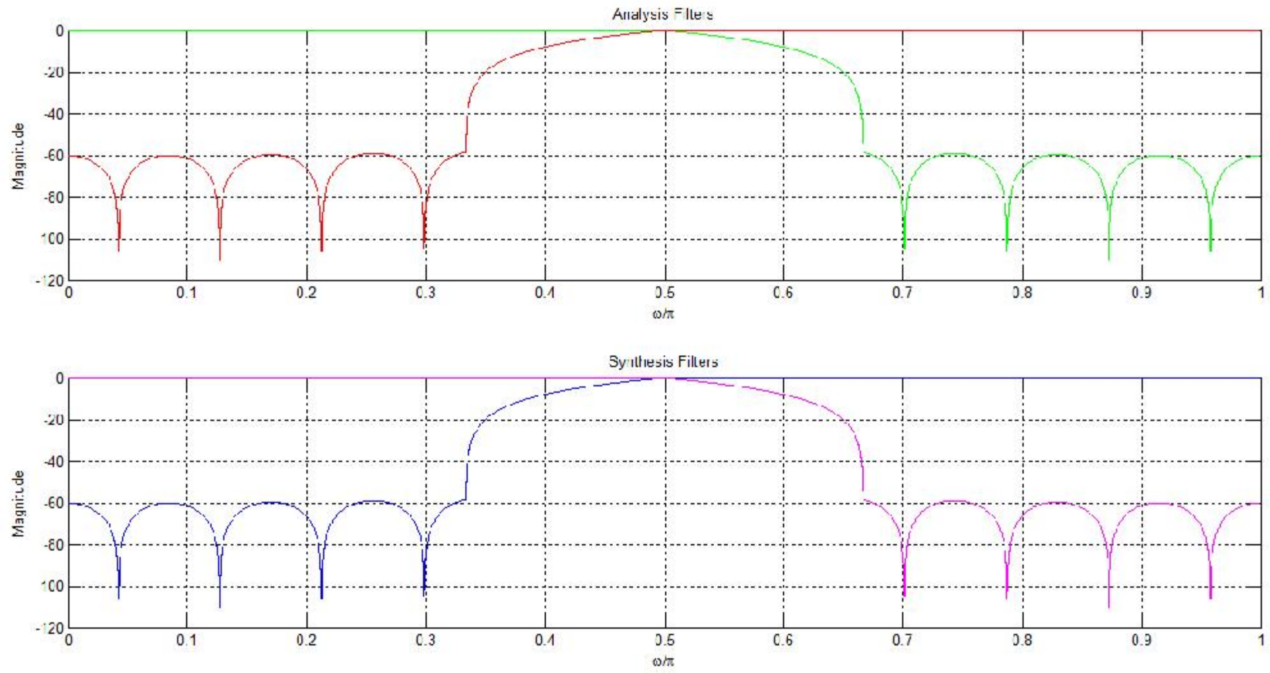

Figure5 Analysis and synthesis response of the first stage of FRM

III. FRM Stage-II

Consider for the implementation of second stage FRM filter that ω_p^1 and ω_s^1 are the pass-band and stop-band frequencies. Complementary filter will also be calculated for second stage FRM filter represented by

$$H_c^1(e^{j\omega}) = e^{\frac{-j\omega(N-1)}{2}} - H(e^{j\omega}) \qquad (6)$$

1st condition: Let us considered θ_1 and ϕ_1 are pass-band and stop-band frequencies from the first stage FRM filter i.e. $\omega_p = \theta_1$ and $\omega_s = \phi_1$. Pass-band and stop-band frequencies again calculated for the second stage masking filters H_{ma}^1 and H_{mc}^1. These are represented as $\omega_{pma}^{11}, \omega_{sma}^{11}$, $\omega_{pmc}^{11}, \omega_{smc}^{11}$ pass-band and stop-band frequencies of H_{ma}^1 and H_{mc}^1 respectively. Now, the relation between these given frequencies and m, M, θ, ϕ expressed below-

$$\omega_p = \theta_1 = \frac{2m\pi+\theta}{M} \;\&\; \omega_s = \phi_1 = \frac{2m\pi+\phi}{M} \qquad (7)$$

IV: FRM Stage-III

For the third stage of implementation pass-band and stop-band frequencies are considered as ω_p^2 and ω_s^2. As per the condition of third stage complementary filter will be calculated as

$$H_c^2(e^{j\omega}) = e^{\frac{-j\omega(N-1)}{2}} - H_1(e^{j\omega}) \qquad (9)$$

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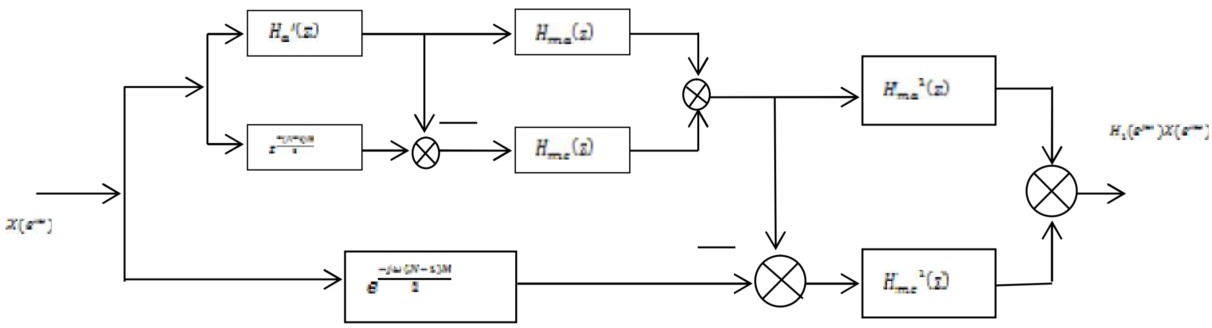

Figure6 second stage of FRM

Table1: Second stage FRM frequency range

Frequency Range/Stages		Stage II	
		Condition 1	Condition 2
Frequency range 1		$0 < \omega < \frac{2m\pi(M-1)-\theta}{M^2}$	$0 < \omega < \frac{2m\pi(M+1)+2m\pi-\phi}{M^2}$
Frequency range 2		$\frac{2m\pi(M-1)+2m\pi-\phi}{M^2} < \omega < \pi$	$\frac{2m\pi(M+1)-\theta}{M^2} < \omega < \pi$
Frequency range 3	Part1	$\frac{2m\pi(M-1)-\theta}{M^2} < \omega < \frac{2m\pi(M+1)+\theta}{M^2}$	$\frac{2m\pi(M+1)+2m\pi-\phi}{M^2} < \omega < \frac{2m\pi(M-1)+\phi}{M^2}$
	Part2	$\frac{2m\pi(M+1)+\phi}{M^2} < \omega < \frac{2m\pi(M+1)+2m\pi-\phi}{M^2}$	$\frac{2m\pi(M-1)+\theta}{M^2} < \omega < \frac{2m\pi(M+1)-\theta}{M^2}$

2nd condition: Similarly for second condition ω_{pma}^{12}, ω_{sma}^{12}, ω_{pmc}^{12},ω_{smc}^{12} are the pass-band and stop-band frequencies of H_{ma}^{1} and H_{mc}^{1} respectively. So,

relation with m, M, θ, ϕ to the frequencies given below-

$$\omega_p = \phi_1 = \frac{2m\pi-\phi}{M} \;\&\; \omega_s = \theta_1 = \frac{2m\pi-\theta}{M} \qquad (8)$$

The above equation (7) and (8) helps to calculate the cutoff frequencies of second stage shown in table (1).

There is final frequencies $\omega_p^1$and ω_s^1 from the second stage that will be consider as input for third stage as θ_2 and ϕ_2 i.e. ($\omega_p^1 = \theta_2$and $\omega_s^1 = \phi_2$). Similar to previous stage implementation here also two conditions will be considered-

1st condition: H_{ma}^{2} and H_{mc}^{2} considered as masking filters of third stage having pass-band and stop-band frequency ω_{pma}^{21}, ω_{sma}^{21}, ω_{pmc}^{21},ω_{smc}^{21}respectively. The condition of input will be considered as $\theta_2 = \omega_p^1$ and $\phi_2 = \omega_s^1$. Now, the relation between these given frequencies and m, M, θ, ϕ expressed.

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2nd condition: For the second condition of third stage ω_{pma}^{22}, ω_{sma}^{22}, ω_{pmc}^{22},ω_{smc}^{22} are the pass-band and stop-band frequencies of H_{ma}^{2} and H_{mc}^{2} respectively. So, relation with m, M, θ, ϕ to the frequencies given as shown in table (2)

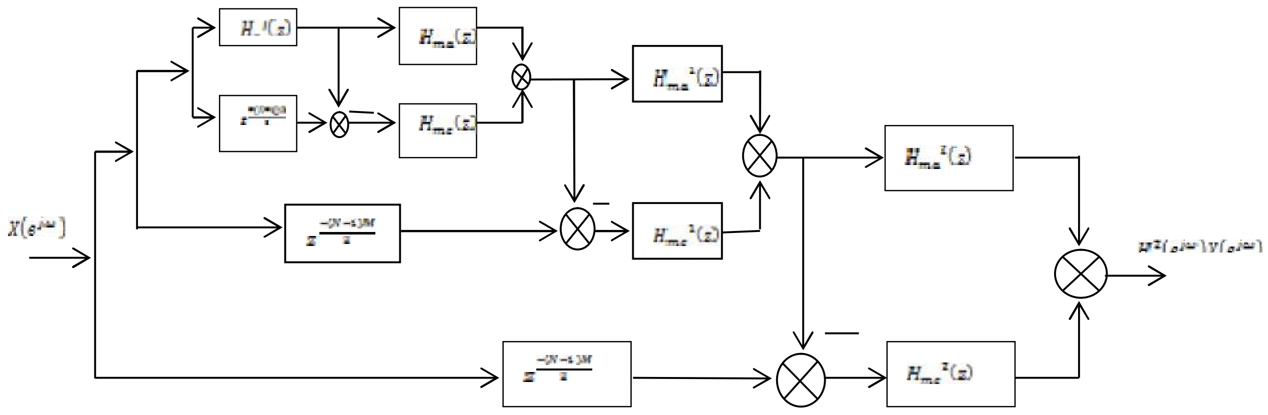

Figure 5: Block diagram of third stage FRM filter

VI. Conclusion

From the calculation of these three stages it has been clear that as the stages are increasing the expected cutoff of the filter will become sharper, but complexity of the structure increases with stages. The rate of iteration will also make the speed slower. This method of designing can be utilized to optimize the OFDM parameters like ISI and ICI. It will give the scope of area to the researchers.

Table3 Third stage of FRM frequency range

Frequency Range/Stages		Stage III	
		Condition 1	Condition 2
Frequency range 1		$0 \leq \omega \leq \frac{2m\pi(M^2 - M - 1) - \theta}{M^3}$	$0 \leq \omega \leq \frac{2m\pi(M^2 + M + 1) + 2\pi M^2 + \phi}{M^3}$
Frequency range 2		$\frac{2m\pi(M^2 - M - 1) + 2\pi M^2 - \phi}{M^3} \leq \omega \leq \pi$	$\frac{2m\pi(M^2 + M - 1) + \theta}{M^3} \leq \omega \leq \pi$
Frequency range 3	Part1	$\frac{2m\pi(M^2 - M - 1) - \theta}{M^3} \leq \omega \leq \frac{2m\pi(M^2 + M + 1) + \theta}{M^3}$	$\frac{2m\pi(M^2 + M + 1) + 2\pi M^2 + \phi}{M^3} \leq \omega \leq \frac{2m\pi(M^2 - M + 1) - \phi}{M^3}$
	Part2	$\frac{2m\pi(M^2 + M + 1) + \phi}{M^3} < \omega < \frac{2m\pi(M^2 - M - 1) + 2\pi M^2 - \phi}{M^3}$	$\frac{2m\pi(M^2 - M + 1) - \theta}{M^3} < \omega < \frac{2m\pi(M^2 + M - 1) + \theta}{M^3}$

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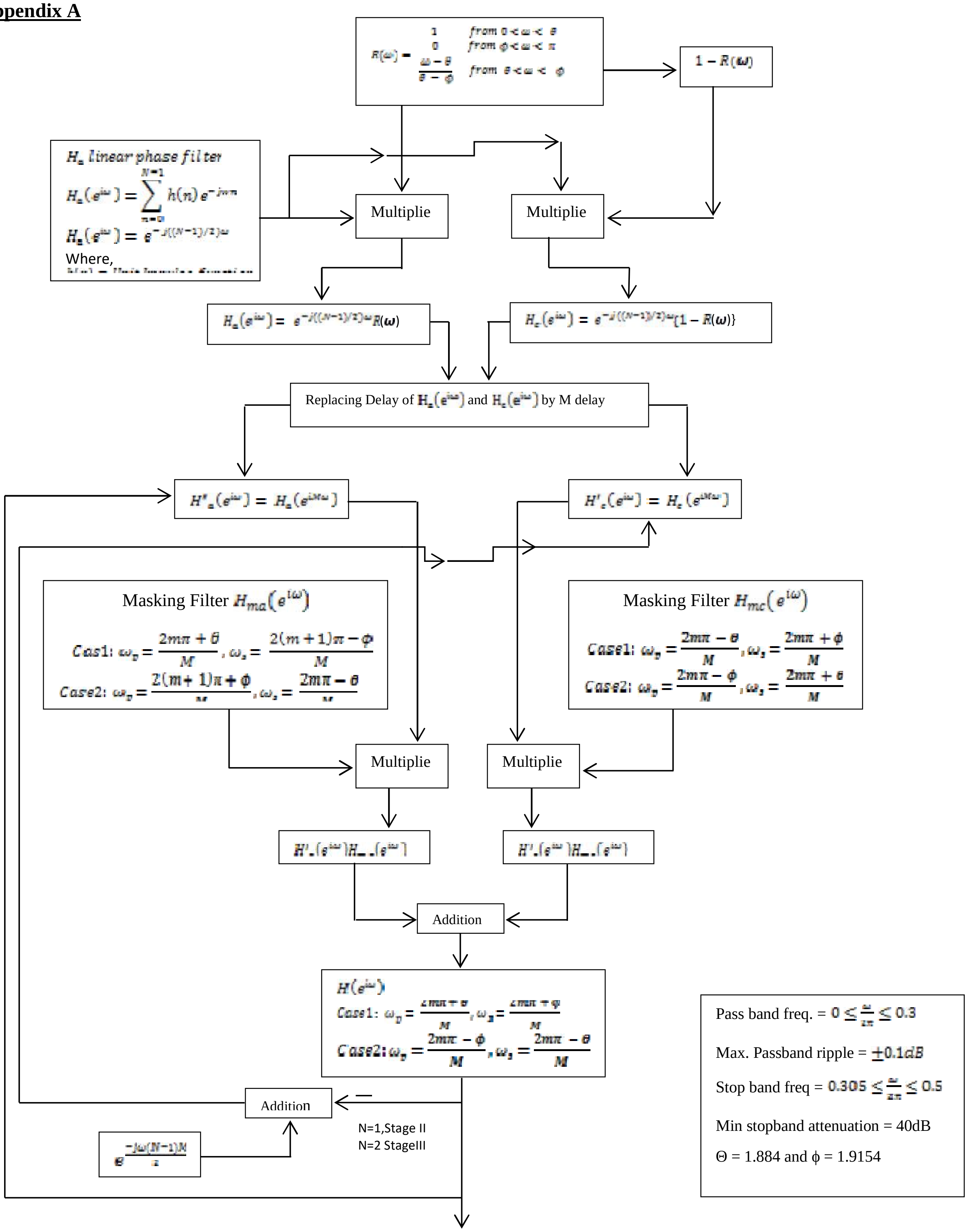
Appendix A



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[3] L R Rabiner and B. Gold "Theory and application of design signal processing" Englewood cliffs,Printice-Hall,1975.

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