One Method for Design of Wide-band FIR Filters using Frequency Masking Method with Rounding and Sharpening

Digital Signal Processing
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***Abstract*—This paper presents a modification of the Frequency Masking Method (FMM) proposed by Yong Ching Lim for Wide-band FIR filters with less multipliers. This method is based on the masking method reducing the complexity, using IFIR filter instead of model filter and applying the rounding and sharpening techniques in all subfilters. The coefficient values of the IFIR and masking filters are represented as integers using the rounding technique. The sharpening technique is applied to improve the magnitude response of rounded IFIR filter and rounded masking filters. Our proposal is to use a set of round constant and sharpening technique to satisfy the overall magnitude characteristics.**

I. INTRODUCTION

For many years has been made methods to reduce the complexity of the FIR filters [1-5]. This finite impulse response (FIR) filters exhibit Linear-phase and stability. A FIR filter of length N require $(N+1)/2$ multipliers, N-1 adders and N-1 delays. The complexity of the implementation increases with the increase in the number of multipliers. The application of frequency-response masking technique for design a sharp FIR filter with a wide-bandwidth was introduced in [5]. The purpose of the method is the reduction of the overall FIR filter. The less order model and masking filters are designed instead of a high order FIR filter. In this paper we propose to further reduce the complexity of the masking method by presenting the substitution of the model filter by a IFIR filter [7], then the filters coefficients are presented as integers using the rounding technique [1], this result in the deteriorated of magnitude characteristic. To resolve this problem we propose to apply the sharpen cascade of L rounded FIR filters, $3H^{2L}$-$2H^{3L}$ [2]. Considering that the integer coefficient multiplications can be accomplished with only shift-and-add operations, the sharpened rounded impulse response filters are multiplier-free [8]. This paper is organized as follows: In section 2 we review briefly the masking method. In section 3 presents the rounding and sharpening techniques and section 4 we proposed described method and illustrated with one example.

II. FREQUENCY MASKING METHOD

The Frequency Masking Method (FMM) [5,7] produce a structure of subfilters, as shown in Figure 1.

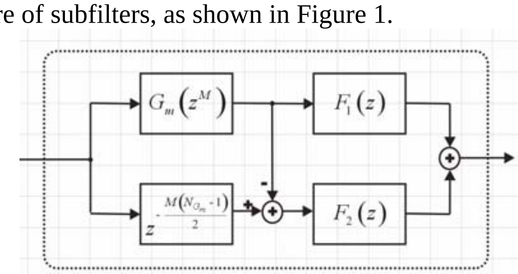

Figure 1: Block diagram of frequency masking filter.

The transfer function of the overall filter is given as [6-8]

$$H_{FMM}(z) = G_m(z^M)F_1(z) + G_c(z^M)F_2(z), \qquad (1)$$

where $G_m(z^M)$ and $G_c(z^M)$ are referred to as the periodic model filter and periodic complementary model filter, respectively, and $F_1(z)$ and $F_2(z)$ as masking filters.

The periodic model filter is $G_m(z^M)$ obtained from the model filter $G_m(z)$ by changing each delay with M delays. The periodic complementary model filter $G_c(z^M)$ is given as [6-8]

$$G_c(z^M) = z^{-M(N_{G_m}-1)/2} - G_m(z^M). \qquad (2)$$

This filter can be implemented by subtracting the output of $G_m(z^M)$ from the delayed version of the input as shown in Fig. 1. More details to obtain the cutoff frequencies of the subfilters can be found in [6].

III. IFIR, ROUNDING AND SHARPENING TECHNIQUES

The Interpolated FIR (IFIR) filter is a structure composed of a cascade of FIR filters:

$$H_{IFIR}(z)=F\left(z^{K}\right)\cdot I(z), \tag{3}$$

where $F\left(z^{K}\right)$ is the expanded filter and $I(z)$ is the interpolator. The filter $F(z)$, is expanded by a interpolation factor K, and $F\left(z^{K}\right)$ is obtained by introducing $K-1$ zeros between each pair of samples of the unit sample response of $F(z)$. The interpolator filter $I(z)$ is designed to attenuate images introduced by $F\left(z^{K}\right)$. More details can be found in [6].

In rounding, the coefficients of the impulse response $h(n)$ are rounded to the nearest integer values. The value which determines the precision of the approximation is called the *rounding constant* r. The impulse response rounding given by

$$h_r(n)=r\cdot h_I(n)=r\cdot round(h(n)/r), \tag{4}$$

where $h_I(n)$ is the impulse response with integer coefficients and $round(.)$ means the rounding operation. The rounding constant r determines the precision of the approximation of $h_r(n)$ to $h(n)$. Considering that the integer coefficient multiplications can be implemented with only shift-and-add operations, the rounded impulse response filter is multiplier-free. An increase in the value of the rounding constant leads to an increase in the number of zero–valued coefficients, this result in the deteriorated of magnitude characteristic.

To resolve this problem we propose apply the sharpening technique for simultaneous improvements of both the passband and stopband characteristics [2].

This technique based on idea of the amplitude change function (ACF) which is a polynomial relationship of the form $H_{sh}=f(H)$ between the amplitudes of the overall and the prototype filters, H_{sh} and H respectively, the order of the H_{sh} is three times that H. To not increase the overall complexity we propose to use the simple polynomial as

$$H_{sh}=3H^{2L}-2H^{3L}, \tag{5}$$

where L is the number of the cascaded filters H.

IV. FILTER DESIGN PROCEDURE

The proposed design procedure consists of the following steps:

1) The interpolation factor *M* is chosen and the subfilters of the FMM filter is designed, i.e. equiriple masking filters $F_1(z)$ and $F_2(z)$ are designed. The model filter is changed by a IFIR filter, the interpolation factor *K* is chosen and the IFIR is designed, i.e. equiriple expanded filter $F(z)$ and $I(z)$ are designed. The starting rounded constant is chosen as *r*=0.001. Higher rounding constant is used for less order filter.
2) The sharpening technique is applied to the filters $F_r(z)$ and $G_r(z)$.
3) Using (2) we find the rounded–sharpened complement of the filter $H_{IFIRrS}(z)=Sh\left\{F_r\left(z^{K}\right)\right\}\cdot Sh\{G_r(z)\}$, denoted as $H_{IFIRrSC}(z)$.
4) We apply the rounding technique in the masking filters resulting in rounded masking filters $F_{1r}(z)$ and $F_{2r}(z)$. A good starting point is *r*=0.01.
5) The sharpening technique is applied to the filters $F_{1r}(z)$ and $F_{2r}(z)$.
6) We find the resulting filter using

$$\begin{aligned}H_m(z)&=H_{IFIRrS}\left(z^{M}\right)Sh\{F_{1r}(z)\}\\&+H_{IFIRrCS}\left(z^{M}\right)Sh\{F_{2r}(z)\}\end{aligned}, \tag{6}$$

as illustrated in Fig. 2, where Sh{.} denotes sharpening.

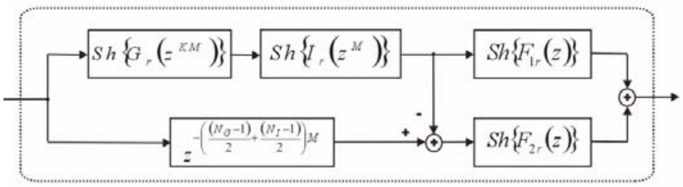

Figure 2: Modified masking filter.

The method is illustrated in the following example.

Example 1:

We design the FIR filter with the normalized passband and the stop band frequencies $\omega_p=0.68$, $\omega_s=0.7$ and the passband ripple $R_p=0.2$ dB and the minimum stopband attenuation $A_s=70$ dB.

The prototype filter designed by Remez algorithm has an order of 256.

Step 1: We choose the interpolation factor *M*=4 and the subfilters of the FMM filter are designed. We use the cutoff frequencies of the model filter and the interpolation factor *K=2* for designed IFIR. We use rounding constant r=0.004 and find the rounded filters $F_r(z)$ and $G_r(z)$ expanded $G_r\left(z^{KM}\right)F_r\left(z^{M}\right)$ filter.

Step 2: The sharpening technique is applied to the filters $H_{iFIRr}(z)=H(z)=F_r(z)$ and $I_r(z)$. And obtained $G_r\left(z^{KM}\right)F_r\left(z^{M}\right)$.

Step 3: Using (2) we find the rounded–sharpened complement of the filter $H_{IFIRrS}(z)=Sh\left\{F_r\left(z^{K}\right)\right\}\cdot Sh\{G_r(z)\}$, denoted as $H_{IFIRrSC}(z)$. The magnitude responses of the rounded–sharpened expanded model filter and its complement are shown in Fig.3.

Step 4, 5: Apply the rounding for masking filters using *r*=0.00286 for the filter $F_1(z)$ and *r*=0.004; then use sharpening technique in rounded masking filters to obtain $Sh\{F_{1r}(z)\}$ and $Sh\{F_{2r}(z)\}$. The magnitude responses of the rounded–sharpened masking filters are shown in Fig. 4.

Step 6:

We find the resulting filter and check if the specification is satisfied.

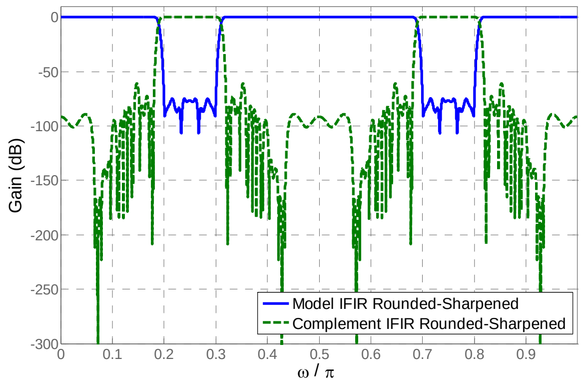

Figure 3: Expanded model IFIR Rounded–Sharpened filter and its complement.

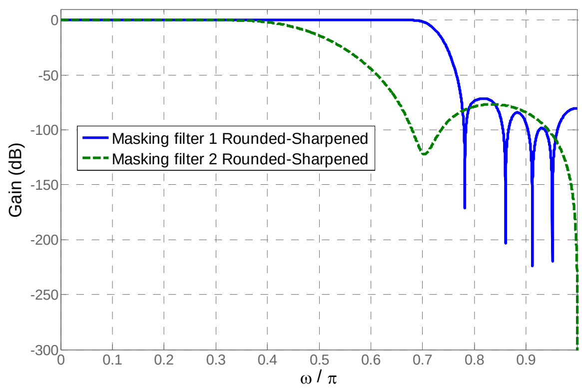

Figure 4: Rounded–Sharpened masking filters.

The resulting magnitude response is given in Fig. 5. The passband and the stopband details demonstrate that the specification is satisfied. Therefore the overall filter designed using the Remez algorithm has 256 adders and 128 multipliers, while the FMM filter has 148 adders and 74 multipliers. The total number of the additions is 312 and the total number of the integer multiplications is 138 in the designed filter. Table 1 presents the numbers of additions, multipliers and the integer multiplications for each structure.

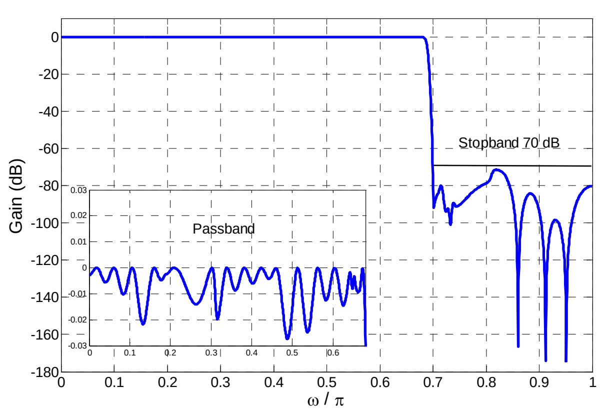

Figure 5: Example 1. Overall magnitude response.

Structure	Filter	Filter Order	Multipliers	Adders
Frequency Masking Method	$G_m(z)$	88	44	88
	$F_1(z)$	46	23	45
	$F_2(z)$	14	7	13
	total	148	74	148
Interpolated-FIR FMM	$G(z)$ / $G_r(z)$	56 / 40	28 / 16	56 / 40
	$I(z)$ / $I_r(z)$	16 / 14	9 / 7	16 / 14
	$F_1(z)$ / $F_{1r}(z)$	46 / 36	24 / 16	46 / 36
	$F_2(z)$ / $F_{2r}(z)$	14 / 14	7 / 7	14 / 14
	$H(z)$ / $H_r(z)$	132 / 104	66 / 46	132 / 104
Modified masking filter.	$Sh\{G_r(z)\}$	120	48	120
	$Sh\{F_r(z)\}$	42	21	42
	$Sh\{F_{1r}(z)\}$	108	48	108
	$Sh\{F_{2r}(z)\}$	42	21	42
	total	312	138	312

Table 1: Number of adders and multiplications.

V. CONCLUSION

In this paper, a modified structure to reduce the complexity of the design of wideband FIR filter using FMM was introduced. The proposed design is based on Interpolated-FIR filters to reduce the complexity of the model filter. The rounding technique approximates the corresponding impulse response with the scaled rounded impulse response with the integer coefficients. The sharpening technique is applied to rounded masking filters to improve the overall magnitude characteristic. The price for introducing the integer multiplications is paid by increasing the number of adders.

VI. REFERENCES

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