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Design of Lowpass Narrowband FIR Filters Using IFIR and Modified RRS Filter

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ABSTRACT
This paper presents a new efficient method for the design of narrowband lowpass (LP) finite impulse response (FIR) filters using a modified interpolated finite impulse response (IFIR) filter and an improved recursive running sum (RRS) filter. Since the number of parameters of the RRS filter is increased the adjustment of the frequency characteristic of the interpolator filter using fewer stages of the RRS filter is possible.

INTRODUCTION
The main disadvantage of FIR filters is that they involve a higher degree of computational complexity comparing to IIR filters with equivalent magnitude response. Many design methods have been proposed to reduce the complexity of FIR filters in the past few years for example (J. W. Adams and A.N.Willson, 1984), (Y.Lian and Y.C.Lim, 1998), (M.E.Nordberg, 1996), (A.Bartolo, B.D.Clymer, 1996) etc. One of the most difficult problems in digital filtering is the design of narrowband filters, (Mitra 2001). The difficulty lies in the fact that such filters require high-order designs in order to meet the desired specification. In turn, high order filters require a large amount of computation so are difficult to implement.

We consider the design of lowpass narrowband FIR filters with cutoff frequencies considerably lower than the sampling rate. One efficient technique for the design of FIR filters is called the interpolation FIR (IFIR) technique (Saramaki at al, 1988). The basic idea is to implement a FIR filter as a cascade of two FIR sections, where one section generates a sparse set of impulse response values and the other section performs the interpolation. Therefore, the IFIR filter is a cascade of two filters

$$H(z) = G(z^M)I(z) \tag{1}$$

where $G(z^M)$ is an expanded shaping or model filter, *I(z)* is an interpolator or image suppressor and *M* is the interpolation factor. The advantage of this structure is based on the design of the prototype FIR filter *H*(*z*) by using smaller order filters *G*(*z*) and *I*(*z*). Further simplification can be obtained using a running sum (RRS) filter as an interpolator, (Dolecek and Reyes, 1999). The system function of the RRS filter is given as

$$H(z) = \left(\frac{1}{M}\frac{1-z^{-M}}{1-z^{-1}}\right)^K = \left(\frac{1}{M}\sum_{n=0}^{M-1} z^{-n}\right)^K \tag{2}$$

where *K* is called the stage. As seen in equation (2), all coefficients are equal to 1 and therefore it is not necessary to apply any multiplication.

The frequency response of the RRS filter can be expressed as:

$$H(e^{j\omega}) = \left\{\frac{sin\dfrac{\omega M}{2}}{Msin\dfrac{\omega}{2}} e^{-j\omega[(M-1)/2]}\right\}^K \tag{3}$$

This is a linear-phase lowpass filter with a very wide transition band, and whose passband is only a small portion of the resulting bandwidth. The frequency response has nulls at integer multiples of 2*p*/*M*. This makes it a natural candidate for elimination of images introduced by $G(z^M)$, provided that the baseband of the filter $G(z^M)$ is narrowband. The RRS filter has only two parameters : *M* and *K,* which must be chosen so that the RRS filter eliminates images of the expanded model filter, and, so that the resulting filter satisfies the given specification. In order to improve the frequency characteristic of the RRS interpolator for a given *M* and *K*, we propose a modification, as described in the next section.

2. MODIFICATION OF RRS FILTER
The parameters of an RRS filter are *M* and *K*. If the specification is not satisfied for a given *M* we must increase *K* to the next integer value. To avoid doing this, we modify the structure of the RRS filter by introducing additional parameters.

We can generate the triangular stepped sequence by multiplying the RRS sequence with the corresponding sparse RRS sequence, as shown in the next equation

$$X(z) = [\sum_{i=0}^{2N-1} z^{-i}]\ [\sum_{k=0}^{N\text{-}1} z^{-2k}] \tag{4}$$

* Note that *N* is an integer.

Using *M*=2*N* according to the equations (2) and (4) we can write the system function of the modified RRS filter

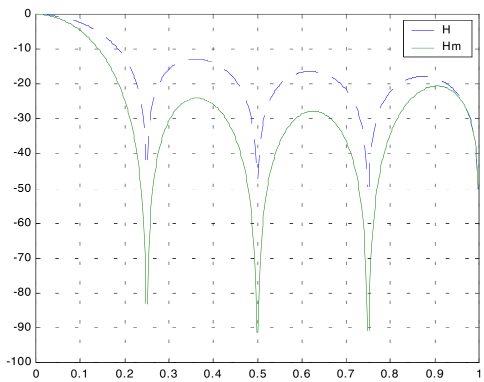
$$H_m(z) = [\frac{1}{M}\sum_{i=0}^{2N-1} z^{-i}]^{k1}\ [\frac{1}{N}\sum_{k=0}^{N\text{-}1} z^{-2k}]^{k2} = H(z)X_1(z) \tag{5}$$

where k_1 and k_2 are the stages. We now have 3 parameters, *M*, k_1, and k_2 which can be used to adjust the frequency characteristic of the interpolator filter in the IFIR structure. Note that the modified RRS filter is a cascade of the original RRS filter and the corresponding sparse RRS filter with the halved order.

Example 1:
We consider *N*=4, k_1=0 and k_2=0 . From (5), we have

$$H_m(z) = [\frac{1}{8}\sum_{i=0}^{2\cdot 4-1} z^{-i}]\ [\frac{1}{4}\sum_{k=0}^{4\text{-}1} z^{-2k}] = H(z)X_1(z). \tag{6}$$

Figure 1: Magnitude responses



The corresponding magnitude responses are shown in Figure 1.
We see that the magnitude response of the RRS filter is improved.

3. PROPOSED STRUCTURE

We propose the modified RRS filter as the interpolator in the IFIR structure. The resulting structure is shown in Figure 2. Adjusting all three parameters of the modified RRS filter we can satisfy the given specification using the lower order interpolator filter.

The method is illustrated in the next example.

Example 2:

We design the filter having these specifications: Passband and the stopband frequencies are w_p=.01 and w_s=.05, respectively. Passband ripple is Rp=0.1 dB and the stopband attenuation is As = 60dB.

The direct design using the Parks McClellan algorithm results in a filter of the order 172. If we use the IFIR structure with the RRS filter and the interpolation factor M=8 we obtain the order of the model filter of only N_G=22. The resulting magnitude response does not satisfy the stopband specification if we use the number of stages k_1=3.

In order to improve the stopband characteristic we use the modified RRS filter with k_1=3, k_2=1 and M=8. The corresponding magnitude response is shown in Figure 3. Observe that the stopband specification is satisfied. Note that the specification is also satisfied using K=4 in the RRS filter, but this filter is more complex than the modified RRS filter with k_1=3 and k_2=1.

Figure 2: Proposed structure

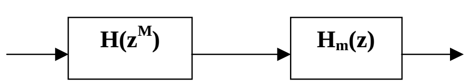
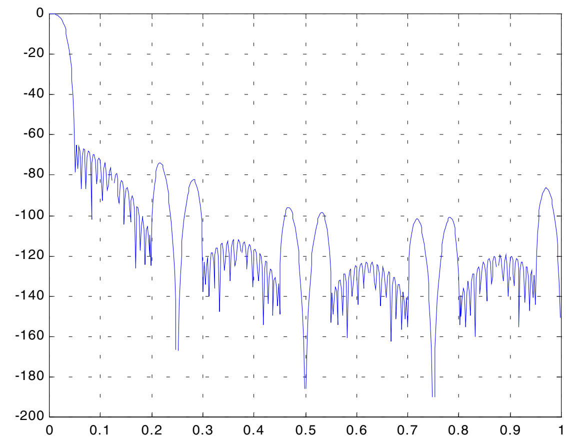


Figure 3: IFIR structure with modified RRS filter M=8, k_1=3, k_2=1



4. CONCLUSIONS

The method for the design of narrowband FIR filters is proposed. It is based on the use of the IFIR structure and the modified RRS filter which is used as an interpolator. The modification of the RRS filter enables decrease in the number of stages of the RRS filter. As a result the given specification is satisfied using less complex interpolator filter making the overall complexity of the design lower. The only restriction is that the interpolation factor in the IFIR structure must be even.

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