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Continuously Variable Bandwidth Filters for Low Complexity Reconfigurable Uniform and Non-Uniform SDR Channelizers

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***Abstract*— In this paper, a hardware efficient low complexity continuously variable band width filter is proposed to be applied in software defined radio channelizers. Uniform and non-uniform reconfigurable filter banks can be obtained using the proposed structure. The proposed structure is compared with the existing structures with design examples. It is observed that the proposed structure has a much lower complexity than the existing methods..**

***Index Terms*— Uniform and Non-uniform filter banks, SDR channelizer, CVBW filters, Farrow structure.**

I. INTRODUCTION

As communication technology continues its rapid transition from analog to digital, most of the functions of the modern radio systems are implemented in software, leading to the software defined radio (SDR)[1], which requires a technology that provides multi-band, multi-standard and multi-services to be realized on a common hardware. The ability to support multiple wireless communication standards is the primary attraction of an SDR. The SDR employs a channelizer to extract the multiple narrowband channels from a wideband signal. The SDR channelizer is nothing but a bank filter with of variable characteristics.

The wireless spectrum is shared among various users. Regulatory bodies allocate a fixed block of the spectrum to a particular service in an area for a long period of time. As a large portion of the assigned spectrum may remain under-utilized, the need is to efficiently allocate them amongst the users. This calls for varying the allocated bands according to the requirement. In addition, flexible communication systems are to be designed to cater to different applications through the same channel. According to the user demands, various bands of signal frequencies are to be channelized into the communication device. This requirement calls for an efficient and tunable matched filter design that can provide alias-free switching between the required standard frequencies, each having different bandwidth. This is the principle of an SDR, which requires the design of a flexible and efficient structure of a radio frequency front-end, for handling a broad range of carrier frequencies and bandwidths [2].

There are variable bandwidth techniques which also alter the center frequencies. Discrete Fourier transform filter banks (DFTFB) basednon-uniform channelization [3], has an advantage of channelizing multiple bands at a time, as with all multi-rate based techniques. The design complexity is very high because it uses separate prototype filters for each stage. An efficient technique to vary the center frequency along with bandwidth is, by employing the coefficient decimation technique (CDM)[4, 5,6]. In the CDM I technique [4], the

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coefficients of a low pass FIR filter are made zero by a factor *M*. If the intermediate values are removed, it results in a response with a passband that is *M* times the original response (CDM II). The various channels are obtained simultaneously using separate masking filters need to be employed.In the CDM method [5], the required centre frequency is obtained by the rule of decimation. Thus, the images formed after performing downsampling, are used. In multi-band communications, the input signals switch to different frequency locations. In such scenario, it is difficult to obtain the desired frequency band channelization. An improved coefficient decimation method (ICDM)technique in [6], to extract various channels from the wideband input. In this paper, an efficient reconfigurable SDR channelizer method is proposed, where all the bands can be varied continuously, with lower hardware complexity.

II. PROPOSED UNIFORM AND NON-UNIFORM FB USING CVBW FILTER

The structure of the continuously variable bandwidth (CVBW) filter structure is given in Fig. 1. The bandwidth of the fixed filter can be varied using a single variable parameter (V) without any hardware changes in the structure [7,8,9,10].

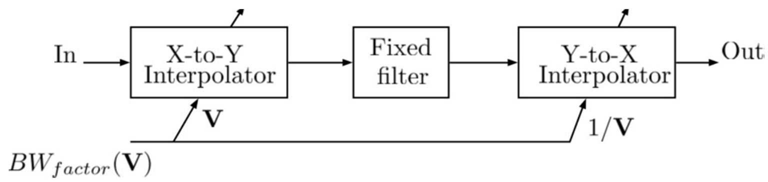

Figure 1. CVBW filter structure

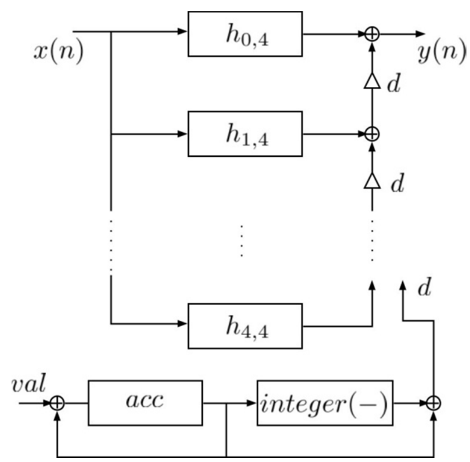

Figure 2. SRC structure for realizing interpolator

The fixed filter is placed between the two interpolators X-to-Y and Y-to-X, respectively. The sample rate conversion(SRC) structure for realizing the interpolator proposed in [9,10], is shown in Fig. 2. A tunable factor, *val*, is given to each interpolator. This gets accumulated to its previous value, to an accumulator memory through every iteration, until the time domain input, $x(n)$, is available, as *accum* = *accum* + *val*. This is fed into the module for integer extraction. Here,the Farrow sub-filters are used to provide a fractional delay, as shown in Fig. 2, where $h_{k,N}$are the Farrow sub-filters with order$N$=4 and k=0,1,..N+1in a Farrow structure filter; whose bandwidth can be varied by a single parameter d as shown in Fig. 2 [9,10,11].To get a variation of the bandwidth of the fixed filter by a factor, the *val* in Fig. 2 to the X-to-Y interpolator is to be given as V and to Y-to-X interpolator as 1/V. The input, In, is a unit impulse response signal. The X-to-Y interpolator in Fig. 1 changes the sample rate of the input. When it is passed through the fixed filter; it gives a sinc signal. When this sinc signal is passed through the Y-to-X interpolator, its main lobe width is altered. This changes the bandwidth of the output signal.

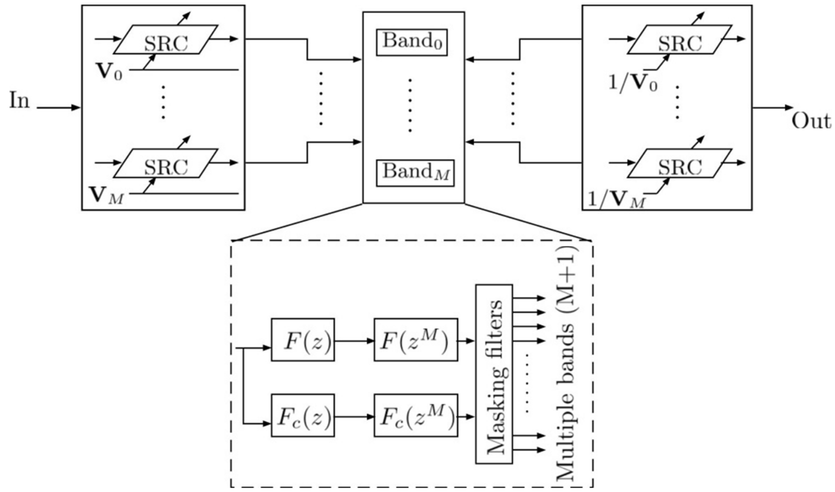

Figure 3. The proposed CVBW filter structure

The proposed structure designed using Fig. 1, is shown in Fig. 3.Here, two sets of interpolators (SRC) are used. The fixed filter is replaced with a structure which generates multiple bands as shown in Fig. 3. The multiple bands are obtained with a prototype filter$F(z)$, a complementary filter $F_c(z)$, and two set of masking filters. *F(z)*is interpolated with a factor *M* value. *M* is selected based on the how many bands are need to be constructed. Similarly, $F_c(z)$, which is obtained from *F(z),* is interpolated with the same factor M. This results in a set of narrow bandwidth filters. By selecting the masking filters,the various bands can be obtained from the interpolated filter. Now, these bands are replaced between the two sets of SRC's as shown in Fig. 3. These bandwidths can be varied by changing the variable parameter (Vmin≤V≤Vmax). When V=Vmin, the fixed filter bandwidth is increased. Similarly, for V=Vmax, the fixed filter bandwidth is decreased.

III. Results and discussion

Two design example are given below to demonstrate working and hardware efficiency of the proposed structure.

A. Example1

The working principle of the proposed structure is explained in this example. Let us assume, that a channel bandwidth of 0.5MHz bandwidth, is desired in a 20 MHz spectrum. Here, the specifications of the desired filter are: passband (PB)ripple of 0.1 dB, stopband(SB) attenuation of 60 dB and 50 kHzpass-bandwidth with cutoff frequency 0.5 MHz are chosen. The PB and SB frequencies of *F(z)*are obtained as $\omega_p = 0.45 \times M$ MHz and $\omega_s = 0.5 \times M$ MHz respectively, where *M* is the interpolation factor M, chosen here as 10.
The frequency response of the prototype filter $F(z)$ia as shown in Fig. 4a. The interpolated filter frequency response is as shown in Fig. 4b. The masking filter is selectedto give a response as shown in Fig. 4c. The resultant overall frequency response is obtained with 0.5 MHz bandwidth as shown in Fig. 4d. The frequency response of the filter can be varied by varying V in the structure in Fig. 1, without any hardware changes. When, V=0.25, the bandwidth of the channel is increased as shown in Fig. 4e., andfor V=1.2, the bandwidth of the channel is decreased as shown in Fig. 4f.

A. Example 2

In this example, the proposed structure is compared with the design example given in [6] to obtain four Bluetooth (BT) channels, one Zigbee channel and one wideband code division multiple access (WCDMA) channel, that are present at different locations in the wideband spectrum. The corresponding bandwidths are 1, 4 and 5 MHz respectively and the sampling frequency is 40 MHz.

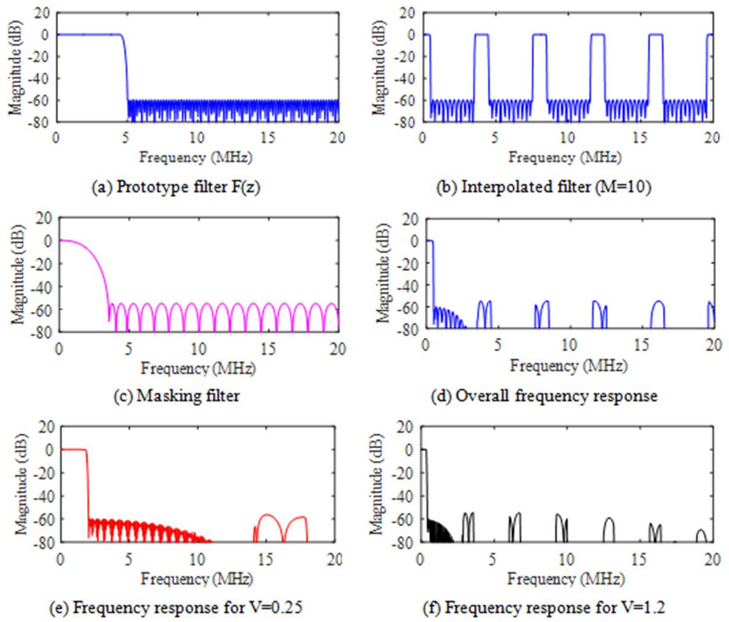

Figure 4. Frequency Responses Of The Proposed Structure

The interpolated and complementary frequency responses of the prototype filter used in Example 1, are as shown in Figs. 5a and 5b respectively.The desired channels are obtained from these responses by selecting the appropriate masking filters. Fig. 5a, shows six bands with 1 MHz bandwidth and centre frequencies at 0, 4, 8, 12, 16 and 20 MHz respectively. Similarly, Fig. 5b, shows five bands with 1 MHz bandwidth and centre frequencies at 2, 6, 10, 14 and 18 MHz respectively. The desired channels are obtained by selecting the respective masking filters as shown in Figs. 5a and 5b respectively. Let say, BT1, BT2, BT3 and BT4 be channels with 1 MHz bandwidth at centre frequencies 2, 4, 6 and 14 MHz respectively. Zigbee with 4 MHz bandwidth andWCDMA with 5 MHz bandwidth can be obtained at centre frequencies 10 and 17.5 MHz respectively. BT1, BT2, BT3 and BT4 are directly obtained after masking the selected bands from the interpolated and complementary interpolated filters as shown in Figs. 5c and 5d respectively.

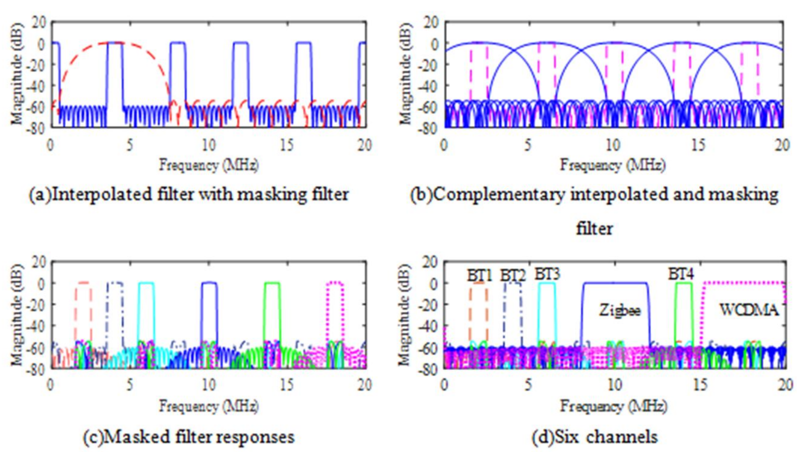

Figure 5. Frequency Responses Of The Proposed Structure

Zigbee and WCDMA channels are obtained using the proposed structure with SRC's, which alters the bandwidth to that of Zigbee (4 MHz) and WCDMA (5 MHz). Here, for V=0.25, Zigbee is obtained. Similarly, WCDMA is obtained with V=0.2. The final spectral response of the wideband input can be extracted into six channels as specified in [6] and are as shown in Fig. 5d. The implementation complexity as compared to [5, 6] is given in Table 1. It has lower complexity and more flexibility compared to the existing CDM and ICDM techniques given in [5, 6]. Further flexibility to obtain other wireless standards that are non-integer multiples of the bandwidth of the fixed filter, is also possible using the proposed structure, which is not possible using CDM and ICDM.

Table 1.Hardware complexity comparison in terms of number of multipliers

	CDFB [5]	ICDMFB [6]	Proposed method
Prototype filter	1545	1465	109
Masking filters	20+60×3	20×4	18×11
SRC	-	-	11×11×2
Total No. of multipliers	1745	1545	549

III. CONCLUSION

A continuously variable bandwidth filter structure is proposed in this paper to result in the reconfigurable channelizers in an SDR, with very low hardware complexity. Here, the bandwidths of the resultant CVBW filter can be continuously varied by a single parameter, without changing the hardware.

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