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Review: Design of Highly Efficient Multirate Digital Filters

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ABSTRACT
In this paper we propose the literature review related to design the multirate digital filters for audio application. One of the main objectives of this survey paper is to find the comparison between various multirate digital filters used in audio applications and communications. Another objective is to provide novel approach in order to help the reader with choosing the most appropriate digital filter for the multirate digital signal processing.
Keywords: Digital Signal Processing, Multirate filter, Sampling rate, FIR and CIC.

I. INTRODUCTION

In many practical application of digital signal processing, there is a problem of changing the sampling rate of a signal, either increasing it or decreasing it by some amount. For example, in telecommunication system that transmits and receives the different types of signals (e.g. fax, speech, video, etc), there is a requirement to process the various signals at the different rates with corresponding bandwidth of the signals. The process of converting a signal from a given rate to a different rate is called as "sampling rate conversion" and the systems that employ multiple sampling rates in the processing of digital signals are called as "Multirate digital signal processing system".

Multirate systems have gained popularity since the early 1980s and they are commonly used for audio and video processing, communications systems, and transform analysis to name but a few [5]. In most applications Multirate systems are used to improve the performance, or for increased computational efficiency. The two basic operations in a Multirate system are decreasing (*decimation*) and increasing (*interpolation*) the sampling-rate of a signal. Multirate systems are sometimes used for *sampling-rate conversion*, which involves both decimation and interpolation [5].

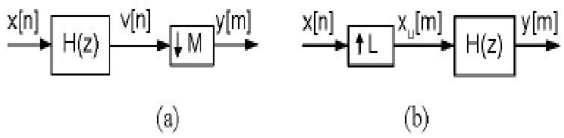

Fig. 1 (a) Decimator (b) Interpolator

1. LITERATURE REVIEW

Sr. no.	Name of Author	Paper Title/Reference	Publication	Approach & Concept about Work	Advantages	Limitations of Works
1.	L.C Loong And N.C Kyun	Design and Development of a Multirate Filters in Software Defined Radio Environment [1]	International Journal of Engineering and Technology, Vol. 5, No. 2, 2008	This paper present the multirate filters design using SDR concept. Two SDR models are considered; one with System Generator and one which was based on Matlab Simulink. The results show that both models can produce the desired audio sample rate.	Using SDR concept, processing can be done at any sampling rate, within a wide range of rates.	Both models are operated at different sampling rates.
2.	Prasit Kumar Bandyopa dhyay And Arindam Biswas	FPGA Based High Frequency Noise Elimination System From Speech Signal Using XILINX System Generator [2]	Journal of Electron Devices, Vol. 17, 2013	In this paper, they discuss the implementation of FIR Bandpass Filters on FPGAs which will eliminate high frequency noise from audio speech signal. This paper describes about the Noise Extraction system that is designed in Xilinx System	They provide excellent high frequency noise reduction.	They required more number of hardware (Multiplier, Accumulator and Dual port RAM).

				Generator software is used to eliminate high frequency noise from audio signal.		
3.	Rajesh Mehra And Rashmi Arora	FPGA-Based Design of High-Speed CIC Decimator for Wireless Applications [4]	International Journal of Advanced Computer Science and Applications, Vol. 2, No. 5, 2011	This paper provided design and implementation of high speed CIC decimator for wireless applications like GSM. The fully pipelined CIC decimator is designed with Matlab, simulated with Xilinx AccelDSP, synthesized with Xilinx Synthesis Tool (XST), and implemented on Virtex-II based XC2VP50-6 target FPGA device.	It reduces the need for expensive anti-aliasing analog filters. It provides enhanced performance in terms of speed and area utilization.	The frequency response is not accurate.
4.	Yonghao Wang and Joshua Reiss	Time domain performance of decimation filter architectures for high resolution sigma delta analogue to digital conversion [9]	Audio Engineering Society Convention Paper 8648 Presented at the 132nd Convention 2012 April	They present the results of a comparison of different decimation architectures for high resolution sigma delta analogue to digital conversion in terms of passband, transition band performance, simulated signal to noise ratio, and computational cost.	They provide excellent comparison of the different multirate filters for low group delay audio applications.	They provide only theoretical overview of different multirate filters.
5.	Rajesh Mehra And Shaily Verma	FPGA Based Design of Direct Form FIR Polyphase Interpolator for Wireless Communication	International Journal of Electrical Electronics &Telecommunication Engineering, 2013	In this paper an Interpolator has been designed and simulated by using Direct Form Polyphase Serial and Parallel structures to reduce area and to enhance speed.	The result shows that serial interpolator can enhance speed by 5.6% as compared to MAC based design.	They required more hardware
6.	Juha Yli-Kaakinen, Ming Hu, Riku Uusikartano, Teemu Kupiainen, and Markku Renfors	Multirate Digital Filter Design for a PAL TV Modulator [20]	IEEE Journals, June 28, 1999	This paper develops a multirate digital filter design for the Vestigial SideBand (VSB) modulator required in the analog TV transmission systems, like PAL. The modulator takes as the input the composite video signal digitized at 13.5MHz sample rate and the output is a VSB signal modulated to the usual 38.9 MHz IF picture carrier frequency and sampled at 121.5 MHz rate.	The resulting design has significantly lower complexity than in the earlier designs using FIR filters and it is quite feasible for implementation as an ASIC or even on an FPGA circuit.	To avoid overflow and to satisfy round-off noise requirements, three more additional bits.
7.	Fredric J. Harris and Michael Rice	Multirate Digital Filters for Symbol Timing Synchronization in Software Defined Radios [3]	IEEE Journal vol. 19, no. 12, December 2001	This paper describes the use of a polyphase filter bank to perform the interpolations required for symbol timing synchronization in a sampled-data receiver. Maximum likelihood timing synchronization techniques can be easily incorporated into the polyphase filter bank in a natural way.	Separate interpolating filter following the matched filter is not required.	Necessary of auxiliary control to adjust the clocking of data into the filter bank for small differences in the sample clock and data clock.

II. MULTIRATE FILTERS

The role of a filter in decimation and interpolation is to suppress aliasing and to remove imaging, respectively. The performance of the system for sampling rate conversion depends mainly by filter characteristics. Since an ideal frequency response is not achievable, the choice of an appropriate specification is the first step in designing a proper filter [6].

For decimation and interpolation filters, and for multirate narrowband filters, additional efficiency may be achieved by cascading several stages, each of them consisting of a sub-filter and down-sampler for decimation and an up-sampler and subfilter for interpolation [7] and [8].

The finite-impulse response (FIR) filters or infinite-impulse response (IIR) filters are used for generating the overall system [6]. In some cases, both filter types are in use for building the overall conversion system. The selection of the filter type depends on the criteria at hand. The advantage of using linear phase FIR filters is that they preserve the waveform of the signal components of interest at the expense of a higher overall complexity compared to their IIR counterparts. However, multirate techniques significantly improve the efficiency of FIR filters that makes them very desirable in practice [6].

The efficiency of FIR filters for sampling rate conversion is significantly improved using the polyphase realization. Filtering is embedded in the decimation/interpolation process and a polyphase structure is used to simultaneously achieve the interpolation/decimation by a given factor but running at a low data rate.

The polyphase structure is obtained when an Nth order filter transfer function is decomposed into M (L) polyphase components, M, L<N. For FIR filters, polyphase decomposition is obtained simply by inspection of the transfer function [14], [8], and [15]. Figure 2 shows the polyphase structures for an Mto 1 decimator and a 1-to-L interpolator. Due to the polyphase multirate implementation, the number of arithmetic operations in a linear phase FIR filter is decreased by a factor M (or L). An effective method, which leads to high efficiency for a high-order FIR filter is proposed in [6].

For multirate IIR filters, several approaches to polyphase decomposition have been developed [6] and [16]. For a rational conversion factor LIM an efficient decomposition of the Nth order IIR filter, based on the method given in [6] is proposed in [16]. Polyphase IIR filters require lower computation rates among the known decimators and interpolators [6]. If a strictly linear phase characteristic is not requested, an IIR filter is an adequate choice. Moreover, an IIR transfer function can be designed to approximate a linear phase in the pass-band [7], [10] and [14].

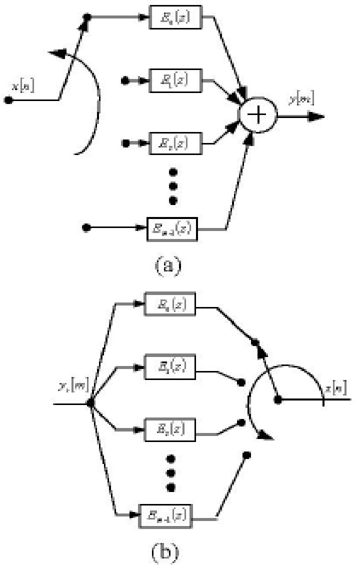

Figure 2. Polyphase structure: (a) Decimator (b) interpolator

III. MULTIRATE COMPLEMENTARY FILTERS

This method can be used in designing filters with any pass-band bandwidth. The multirate techniques are included to reduce the computational complexity. Using the complementary property, the multirate, narrow pass-band filter designs can be used to develop high-pass and low-pass filters with wide pass-bands [6], [11]. When the output of a lowpass multirate filter is subtracted from the delayed replica of the input signal, the result is a wideband high-pass filter. The delay has to be selected to exactly equal the group delay of the multirate filter. For a low-pass wideband filter the multirate narrowband high-pass filter has to be used. Efficient FIR filters with an arbitrary bandwidth can be designed using multirate and complementary filtering [6], [11].

The overall design is evaluated by cascading complementary multirate filtering two-ports composed of two series branches and one parallel branch. The cascade is terminated with a simple kernel filter. One series branch of the cascade is a decimator (filter and down-sampler), while the other is an interpolator (up-sampler and filter). The parallel branch is a delay. The most efficient solution is obtained when half-band filters are used in the cascade.

IV. HALF-BAND FILTERS

Half-band filters are basic building blocks in multirate systems. A *half–band filter* divides the basis band of a discrete-time system in two equal bands with symmetry properties [11]. The FIR filters are most often used as half-band filters. For a linear-phase FIR half-band filter, half of the constants are zero valued when the filter order is an even number [8]. A half-band IIR filter can have fewer multipliers than the FIR filter for the same sharp cutoff specification.

An IIR elliptic half-band filter when implemented as a parallel connection of two all-pass branches is an efficient solution [12]. The main disadvantage of elliptic IIR filters is their very nonlinear phase response. To overcome the phase distortion one can use optimization to design an IIR filter with an approximate linear phase response or one can apply the double filtering with the block processing technique for real-time processing [8].

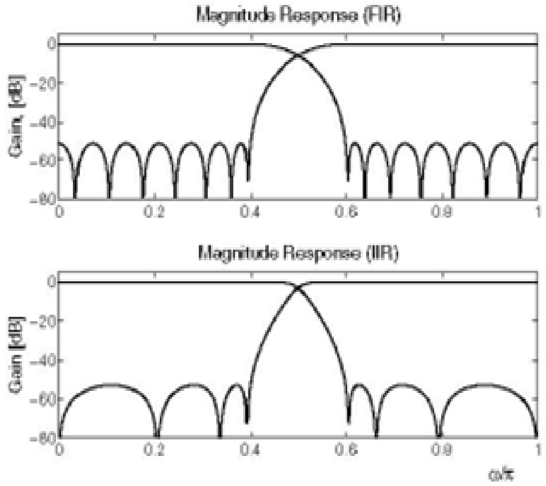

Figure 3. Efficient half-band filter pairs

V. MULTIPLIERLESS SOLUTION

In [1981], an efficient way of performing decimation and interpolation was introduced. Hogenauer devised a exible, multiplier-free filter suitable for hardware implementation, that can also handle arbitrary and large rate changes. These are known as "cascaded integrator comb filters, or CIC filters" [18].

The efficiency of multirate filters is greatly improved by simplifying arithmetic operations. This is achieved by replacing a multiplier with a small number of shifters-and-adders [13]. Generally, implementing multiplierless design techniques in sub-filters, at the cost of a slight derogation of filtering performances, increases the efficiency of the overall multirate filter. For instance, one can use the optimization technique [6], the multiplier block approach or design based on EMQF (Elliptic Minimal Q-Factors) transfer functions [13] and [17]. A well-known solution for large conversion factors in decimation is a cascaded integrated comb (CIC) filter, which performs multiplierless filtering [6], [13], [18].

VI. NEED FOR THE STUDY

Multirate filtering techniques are widely used in both sampling rate conversion systems and in constructing filters with equal input and output rates in the case where the use of a conventional method becomes extremely costly [6]. Thus to design and development of highly efficient multirate digital filter in terms of power consumption and excellent frequency response, the various types of multirate filters are discuss here.

VII. CONCLUSION

The multirate filtering techniques are widely used in sampling rate conversion systems, and for constructing filters with equal input and output sampling rates. Various multirate design techniques provide that the overall filtering characteristic is shared between several simplified subfilters that operate at the lowest possible sampling rates. Hence, by using the multistage approach, the total number of coefficients is significantly reduced. Also there are some multirates filters that are provide the excellent frequency response with consuming less power.

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