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An Improved Coefficient Decimation Based Reconfigurable Low Complexity Wrapped Filter Implementation

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Abstract: **Variable digital filters (VDF) are the digital filters that are used in most signal processing applications whose frequency specifications such as cut-off frequency f_c can be controlled. The warped filters, obtained by replacing each unit delay of a digital filter with an all-pass filter, are widely used for various audio processing applications such as linear prediction, echo cancellation, loudspeaker equalization, spectrally modifying an audio signal and detection of band pass signals in broadband signals. However, warped filters require first-order all-pass transformation to obtain variable low-pass or high-pass responses, and second-order all-pass transformation to obtain variable bandpass or bandstop responses. To overcome this we design a Digital Warped filter.**

I. INTRODUCTION

In many practical scenarios, it is desirable to change the cut-off frequency of a digital filter in real time with minimal overhead on complexity. Such a filter with variable cut-off frequency f_c is called as Variable Digital Filter (VDF). One particular type of VDF is a warped filter, obtained by replacing each unit delay of a digital filter with the all-pass structure of an appropriate order. By changing the coefficients of an all-pass structure, the *fc* of the warped filter can be controlled on the fly. Warped filters are widely used for various audio applications such as linear prediction, echo cancellation, loudspeaker equalization, spectrally modifying an audio signal, detection of band-pass signals in broadband signals, and so on.

Depending on the application, W-FIR filters with variable low-pass, high-pass, band-pass or band-stop responses can be designed. The ideal approach to design W-FIR with variable band-pass response is to replace each unit delay with a second order all-pass transformation. It consists of variable low-pass, band-pass and high-pass filters in parallel. However, the complexity of the band-pass filter, which uses second order all-pass transformation, almost double than that of filters where first order all-pass transformation is used.

Adaptive filters are designed using warping technique to detect the band-pass signals in a broadband signals. The adaptive filters are W-FIR filters designed using reduced second order transformation and hence they provide fixed bandwidth band-pass responses at an arbitrary center frequency. Whenever the bandwidth needs to be changed, the filter coefficients will need to be updated, which incurs a large number of memory read and write operations. A number of different approaches to VDF design are available. They include

1. Transformation approaches ,
2. Farrow structure-based approaches and
3. Frequency response masking-based approach.

Most of these VDFs are commonly used for communication applications due to their exact linear phase characteristics. However, they are not the preferred choice for audio applications because of limited band-pass frequency range and high complexity compared to warped filters, coefficient decimation (CDM) technique for realizing low-complexity VDFs with fixed coefficients is proposed.

II. WARPED FILTER

The frequency warping technique was proposed and further studied where, an FIR filter (also called as prototype filter) with impulse response *h(n)* and its z-transform *H(z)* is considered. Let *G(z)* be the W-FIR version of *H(z)* obtained by replacing every delay with first order all-pass structure, *A(z)*.

$$G(z) = H(A(z))$$

where

$$A(z) = \left(\frac{-\alpha + z^{-1}}{1 - \alpha z^{-1}}\right) \quad |\alpha| < 1. \tag{1}$$

Here, α is the warping coefficient which controls the warped frequency response. For $-1 < \alpha < 0$, the transformation is backward, which means the new fc is smaller than the original fc, and for $0 < \alpha < 1$, the effect is the reverse, that is, the transformation is forward, which means the new fc is higher than the original fc.

There are various implementations available for A(z) . Since the multiplication is the most complex operation in field-programmable gate array (FPGA) implementation of a digital filter, the single multiplier all-pass structure is used. The warped filter is obtained by first designing the Nth-order prototype filter with cutoff frequency fc0 and coefficients h_0, h_1 …h_N in the transposed direct form and then replacing each unit delay with the A(z) shown in Fig 1. By changing α, the cutoff frequency $f_{c\alpha}$ changes. When α = 0, the warped filter as shown in Fig 2 is reduced to an FIR filter [i.e., H(z)] with unit delay and the cutoff frequency f_{c0} .

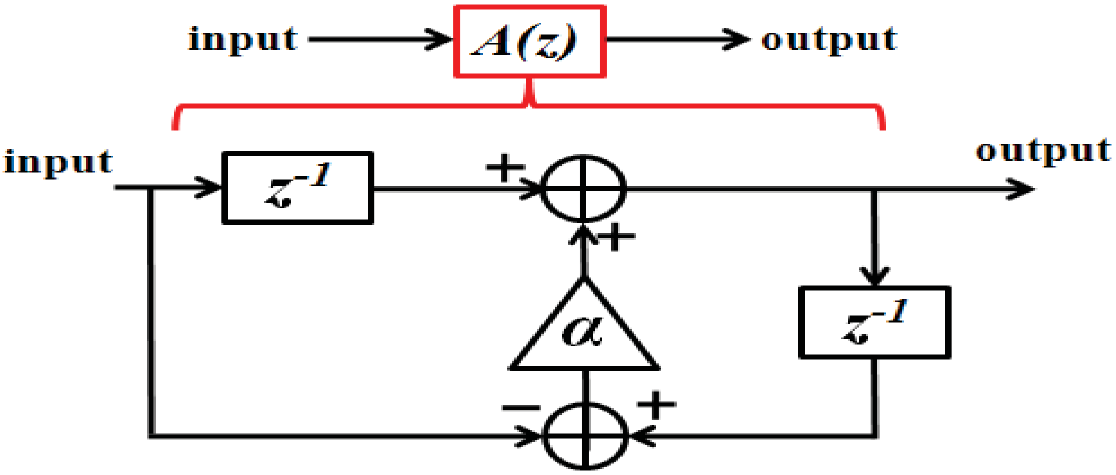


Fig 1: First-order single-multiplier structure for A(z).

Depending upon the type of the prototype filter, the variable low-pass, high-pass, bandpass, or bandstop responses can be obtained at the output. When the prototype filter is a bandpass filter, the output responses are variable bandpass responses. In bandpass responses, there are two variable parameters, center frequency and the bandwidth, and only one controlling parameter, α. For example, consider the prototype bandpass filter with center frequency and bandwidth as 0.49 and 0.04 respectively. All the frequency edges mentioned here are normalized with respect to half of the sampling frequency. It can be observed that the W-FIR filter fails to provide variable bandwidth bandpass responses for a given center frequency.

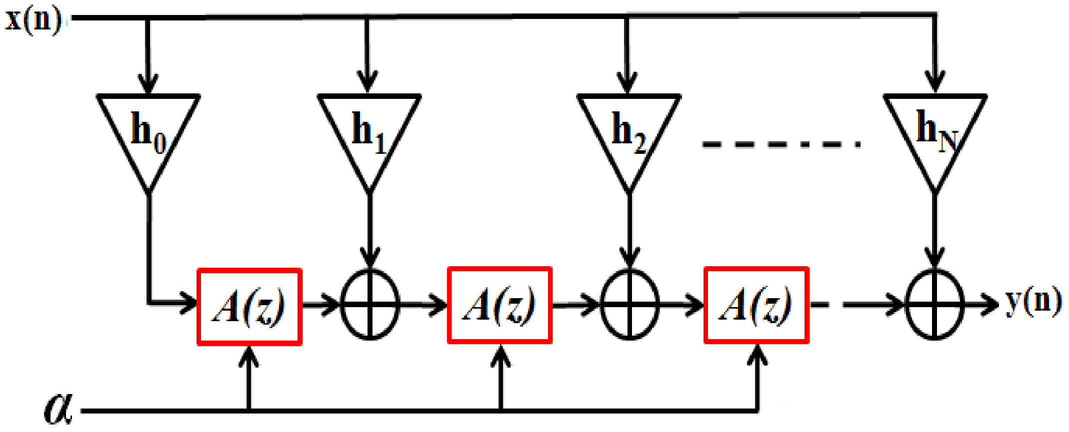


Fig 2: Warped Digital filter

III. CDM TECHNIQUE

The CDM technique provides a decimated version of the original frequency response whose passband width is M times that of prototype filter, where M is the integer decimation factor. In CDM, every M^{th} coefficients of the prototype filter are grouped together discarding in between coefficients. It can be observed that the CDM alone fails to design VDFs with fine control over fc, that is, the fc obtained for different values of M are relatively far apart.

IV. VDF

The main motive of VDF is to obtain variable low-pass, high-pass, bandpass, and bandstop responses on the fly from a fixed-coefficient low-pass filter. In this brief, only warped FIR filter design is considered. The proposed approach can also be extended to the design of warped IIR filters.

4.1 Design method of VDF

Consider an *N*th-order low-pass prototype filter *H(z)* with cutoff requency $\omega_{c0}(= 2\pi f_{c0})$ and coefficients $h_0, h_1, \ldots, h_N$. The proposed VDF architecture is shown in the below fig. The filter coefficients are fixed and hence can be hardwired. The CDM is implemented using the multiplexers controlled by signal *sel_m*. The *sel_m* values for each *M* are stored in the lookup table (LUT). The word length of the stored value in LUT is equal to $N + 1$. For example, when $M = 1$, 2, and 3, the LUT output will be "000…0," "10101…0," and "110110…0," respectively. The multiplexers select signals, *sel_ f* 1 and *sel_ f* 2, decide the type of the output response. The values of *sel_ f* 1 and *sel_ f* 2 to obtain low-pass, high-pass, bandpass, and bandstop responses are {1, 1}, {0, 1}, {0, 0}, and {1, 0}, respectively.

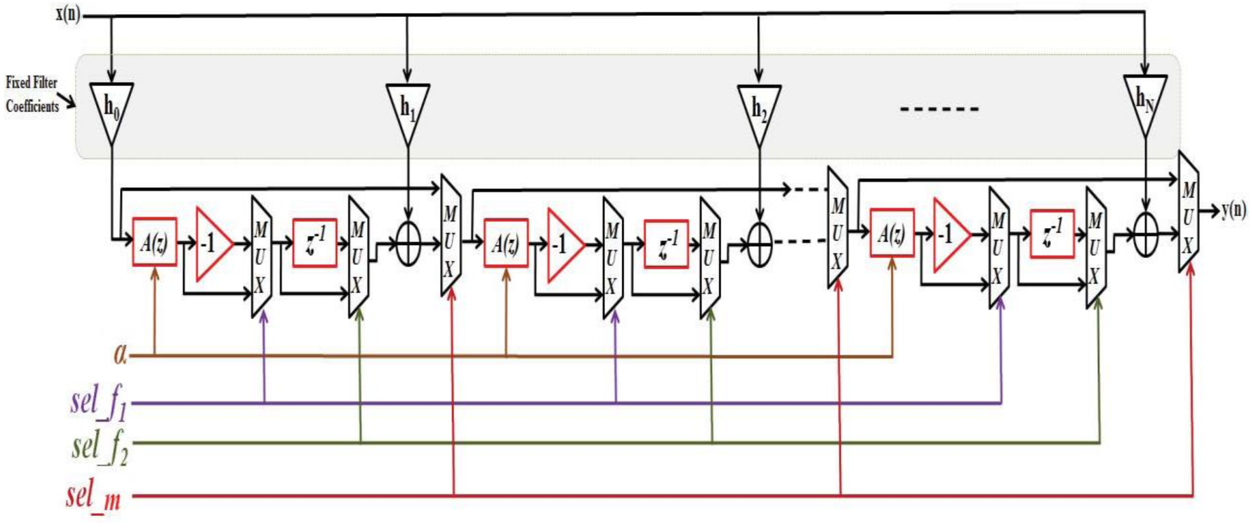


Fig 3: Variable Digital Filter

4.2 Different Variable frequencies

Variable high-pass responses are obtained using the transformation given as [1]

$$G(z) = H(-A(z)). \qquad (1)$$

Fixed-bandwidth bandpass responses at an arbitrary center frequency are obtained using the reduced secondorder transformation given as [1]

$$G(z) = H(B(z)) \qquad (2)$$

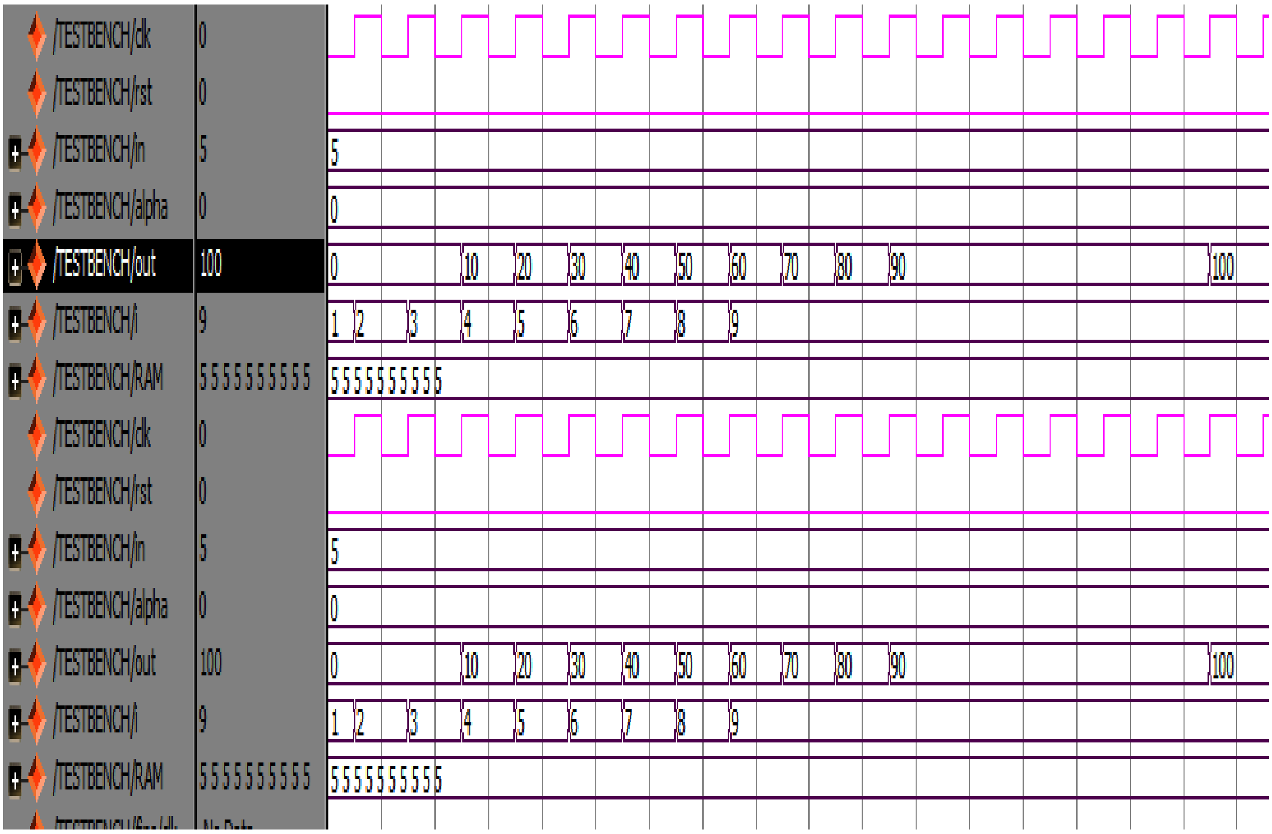
Where,

$$B(z) = -z^{-1}\left(\frac{-a+z^{-1}}{1-az^{-1}}\right) \quad |a|<1 \; = -z^{-1}A(z). \qquad (3)$$

Fixed-bandwidth bandstop responses at an arbitrary center frequency are obtained using the transformation given as [1]

$$G(z) = H(-B(z)). \qquad (4)$$

A computationally efficient VDF using warped filter and CDM technique was presented in this brief. The design example showed that the proposed VDF is simple to design and provides better performance than other approaches. The proposed architecture provides variable low-pass or high-pass responses with fine control over cut-off frequency and variable bandpass or bandstop responses at an arbitrary center frequency without updating the filter coefficients or filter structure as below:



For f0=2’b00 - all taps will be used for filter output.

For f1=2’b01 - Every second tap will be used.

For f3=2’b10 - Every third tap will be used.

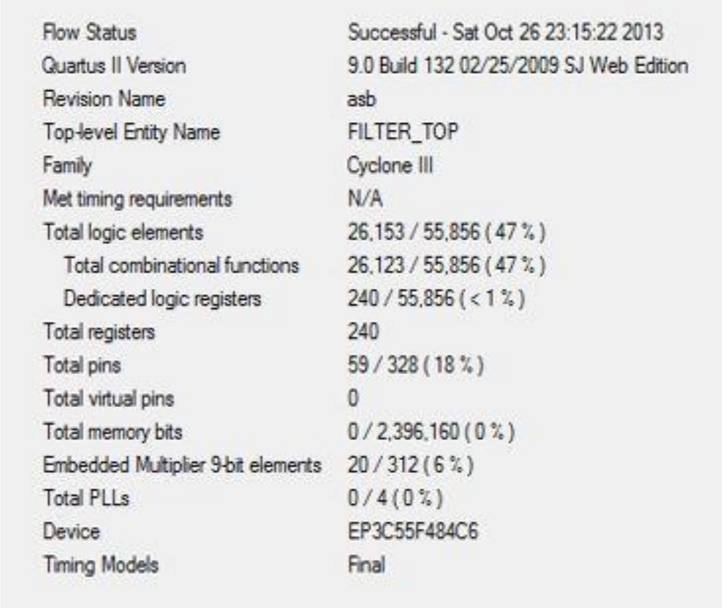
For f4=2’b11 - Every fourth tap will be used

4.3 Area Report for the Proposed VDF

4.3.1 Area for Warped digital filter

Flow Status	Successful - Sat Oct 26 11:28:30 2013
Quartus II Version	9.0 Build 132 02/25/2009 SJ Web Edition
Revision Name	ku
Top-level Entity Name	FILTER_TOP
Family	Cyclone III
Met timing requirements	N/A
Total logic elements	12,847 / 24,624 (52 %)
Total combinational functions	12,833 / 24,624 (52 %)
Dedicated logic registers	146 / 24,624 (< 1 %)
Total registers	146
Total pins	57 / 157 (36 %)
Total virtual pins	0
Total memory bits	0 / 608,256 (0 %)
Embedded Multiplier 9-bit elements	10 / 132 (8 %)
Total PLLs	0 / 4 (0 %)
Device	EP3C25F256C6
Timing Models	Final

4.3.2 Area for Variable digital filter



Flow Status	Successful - Sat Oct 26 23:15:22 2013
Quartus II Version	9.0 Build 132 02/25/2009 SJ Web Edition
Revision Name	asb
Top-level Entity Name	FILTER_TOP
Family	Cyclone III
Met timing requirements	N/A
Total logic elements	26,153 / 55,856 (47 %)
Total combinational functions	26,123 / 55,856 (47 %)
Dedicated logic registers	240 / 55,856 (< 1 %)
Total registers	240
Total pins	59 / 328 (18 %)
Total virtual pins	0
Total memory bits	0 / 2,396,160 (0 %)
Embedded Multiplier 9-bit elements	20 / 312 (6 %)
Total PLLs	0 / 4 (0 %)
Device	EP3C55F484C6
Timing Models	Final

V. CONCLUSION

A computationally efficient VDF using warped filter and CDM technique was presented in this brief. The proposed architecture provideed variable low-pass or high-pass responses with fine control over cut-off frequency and variable bandpass or bandstop responses at an arbitrary center frequency without updating the filter coefficients or filter structure. The noise in the existing system of the 10 tap VDF is reduced in this proposed architecture VDF using CDM technique. The design example showed that the proposed VDF is simple to design and provides better performance than other approaches.

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