Review Paper on High Performance Integrated Circuit for Finite Impulse Response Filter

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ABSTRACT: This paper presents efficient modified distributed arithmetic (MDA)-based approaches for low delay reconfigurable implementation of finite impulse response (FIR) filters whose filter coefficients change during runtime. Conventionally, for reconfigurable DA-based implementation of FIR filter, the lookup tables (LUTs) are required to be implemented in ROM; and the ROM-based LUT is found to be costly for application specific integrated circuit (ASIC) implementation. Therefore, a shared-LUT design is proposed to realize the MDA computation. Instead of using separate registers to store the possible results of partial inner products for DA processing of different bit positions, registers are shared by the DA units for bit slices of different weightage.

KEYWORDS: Finite Impulse Response (FIR), Look Up Table (LUT), Modified Distributive Arithmetic Technique

I. INTRODUCTION

Reconfigurable finite impulse response (FIR) filter whose filter coefficients change dynamically during runtime plays an important role in the software defined radio (SDR) systems [1], [2], multi-channel filters [3], and digital up/down converters [4]. However, the well-known multiple constant multiplication (MCM)-based technique [5] which is widely used for the implementation of FIR filters cannot be used when the filter coefficients change dynamically. On the other hand, general multiplier-based structure requires a large chip area, and consequently enforces limitation on the maximum possible order of the filter that can be realized for high-throughput applications. Distributed arithmetic (DA)-based technique [6] has gained substantial popularity, in recent years, for their high throughput processing capability and increased regularity which result in cost-effective and area-time efficient computing structures. The main operations required for DA-based computation are a sequence of lookup-table (LUT) accesses followed by shift-accumulation operations of the LUT output. The conventional DA implementation used for the implementation of FIR filter assumes that impulse response coefficients are fixed and this behavior makes it possible to use ROM-based LUTs. The memory requirement for DA-based implementation of FIR filters, however, increases exponentially with the filter order. To get rid of the problem of such large memory requirement, systolic decomposition techniques are suggested by Meher et al. for DA-based implementation of long-length convolutions and FIR filter of large orders [7], [8]. For reconfigurable DA-based FIR filter whose filter coefficients change dynamically, we need to use rewritable RAM based LUT [9] instead of ROM-based LUT. Another approach is to store the coefficients in the analog domain by using serial digital-to-analog converters resulting in mixed-signal architecture [10]. We also find quite a few works on DA based implementation of adaptive filters [11], [12] where the coefficients change at every cycle. In this paper, we present efficient schemes for the optimized shared-LUT implementation of reconfigurable FIR filters using DA technique where LUTs are shared by the DA units for bit slices of different weightage. Also, the filter coefficients can be changed dynamically in runtime with very small reconfiguration latency. In the next section, we briefly discuss the mathematical background of DA-based implementation of FIR filter.

II. LITERATURE REVIEW

Basant Kumar Mohanty et al. [1], transpose form finite-impulse response (FIR) filters are inherently pipelined and support multiple constant multiplications (MCM) technique that results in significant saving of computation. However, transpose form configuration does not directly support the block processing unlike direct form configuration. In this paper, we explore the possibility of realization of block FIR filter in transpose form configuration for area-delay efficient realization of large order FIR filters for both fixed and reconfigurable applications. Based on a detailed computational analysis of transpose form configuration of FIR filter, we have derived a flow graph for transpose form block FIR filter with optimized register complexity. A generalized block formulation is presented for transpose form FIR filter.

We have derived a general multiplier-based architecture for the proposed transpose form block filter for reconfigurable applications. A low-complexity design using the MCM scheme is also presented for the block implementation of fixed FIR filters. The proposed structure involves significantly less area delay product (ADP) and less energy per sample (EPS) than the existing block implementation of direct-form structure for medium or large filter lengths, while for the short-length filters, the block implementation of direct-form FIR structure has less ADP and less EPS than the proposed structure. Application specific integrated circuit synthesis result shows that the proposed structure for block size 4 and filter length 64 involves 42% less ADP and 40% less EPS than the best available FIR filter structure proposed for reconfigurable applications. An advantage of this module is used to constant multiplier technique and reduces complexity of the system but disadvantage of this module is high delay.

B. Madhu Latha et al. [2], this brief proposes a two-step optimization technique for designing a reconfigurable VLSI architecture of an interpolation filter for multi standard digital up converter (DUC) to reduce the power and area consumption. The proposed technique initially reduces the number of multiplications per input sample and additions per input sample by 83% in comparison with individual implementation of each standard's filter while designing a root-raised-cosine finite-impulse response filter for multi standard DUC for three different standards. In the next step, a 2-bit binary common subexpression (BCS)-based BCS elimination algorithm has been proposed to design an efficient constant multiplier, which is the basic element of any filter. This technique has succeeded in reducing the area and power usage by 41% and 38%, respectively, along with 36% improvement in operating frequency over a 3-bit BCS-based technique reported earlier, and can be considered more appropriate for designing the multi standard DUC. An advantage of this module is used to 2-bit binary common subexpression technique and reduces area and power of the system but disadvantage of this module is not used to higher bit.

Sang Yoon Park et al. [3], this paper presents efficient distributed arithmetic (DA)-based approaches for high-throughput reconfigurable implementation of finite impulse response (FIR) filters whose filter coefficients change during runtime. Conventionally, for reconfigurable DA-based implementation of FIR filter, the lookup tables (LUTs) are required to be implemented in RAM; and the RAM-based LUT is found to be costly for ASIC implementation. Therefore, a shared-LUT design is proposed to realize the DA computation. Instead of using separate registers to store the possible results of partial inner products for DA processing of different bit positions, registers are shared by the DA units for bit slices of different weightage. The proposed design has nearly 68% and 58% less area-delay product, and 78% and 59% less energy per sample than DA-based systolic structure and carry saved adder (CSA)-based structure, respectively for the ASIC implementation. A DRAM-based design is also proposed for the FPGA implementation of the reconfigurable FIR filter which supports up to 91 MHz input sampling frequency, and offers 54% and 29% less the number of slices than the systolic structure and the CSA-based structure, respectively when implemented in Xilinx Virtex-5 FPGA device (XC5VSX95T-1FF1136). An advantage of this module is used to carry save adder technique and reduces delay and power of the system but disadvantage of this module is large area size of the module.

Basant K. Mohanty et al. [4], we have analyzed memory footprint and combinational complexity to arrive at a systematic design strategy to derive area-delay-power-efficient architectures for two-dimensional (2-D) finite impulse response (FIR) filters. We have presented novel block based structures for separable and non-separable filters with less memory footprint by memory sharing and memory-reuse along with appropriate scheduling of computations and design of storage architecture. The proposed structures involve times less storage per output (SPO), and nearly times less energy consumption per output (EPO) compared with the existing structures, where is the input block-size. They

involve times more arithmetic resources than the best of the corresponding existing structures, and produce times more throughput with less memory band-width (MBW) than others. We have also proposed separate generic structures for separable and non-separable filter-banks, and a unified structure of filter-bank constituting symmetric and general filters. The proposed unified structure for 6 parallel filters involves nearly times more multipliers, times more adders, less registers than similar existing unified structure, and computes times more filter outputs per cycle with times less MBW than the existing design, where is FIR filter size in each dimension. ASIC synthesis result shows that for filter size (4 4), input-block size, and image-size (512 512), proposed block-based non-separable and generic non-separable structures, respectively, involve 5.95 times and 11.25 times less area-delay-product (ADP), and 5.81 times and 15.63 times less EPO than the corresponding existing structures. The proposed unified structure involves 4.64 times less ADP and 9.78 times less EPO than the corresponding existing structure. An advantage of this module is used to memory based design and reduces memory of the system but disadvantage of this module is large complexity of the module.

Basant K. Mohanty et al. [5], in this paper, we present an efficient distributed arithmetic (DA) formulation for the implementation of block least mean square (BLMS) algorithm. The proposed DA-based design uses a novel look-up table (LUT)-sharing technique for the computation of filter outputs and weight-increment terms of BLMS algorithm. Besides, it offers significant saving of adders which constitute a major component of DA-based structures. Also, we have suggested a novel LUT-based weight updating scheme for BLMS algorithm, where only one set of LUTs out of sets need to be modified in every iteration, where , , and are, respectively, the filter length and input block-size. Based on the proposed DA formulation, we have derived a parallel architecture for the implementation of BLMS adaptive digital filter (ADF). Compared with the best of the existing DA-based LMS structures, proposed one involves nearly times adders and times LUT words, and offers nearly times throughput of the other. It requires nearly 25% more flip-flops and does not involve variable shifters like those of existing structures. It involves less LUT access per output (LAPO) than the existing structure for block-size higher than 4. For block-size 8 and filter length 64, the proposed structure involves 2.47 times more adders, 15% more flip-flops, 43% less LAPO than the best of existing structures, and offers 5.22 times higher throughput. The number of adders of the proposed structure does not increase proportionately with block size; and the number of flip-flops is independent of block-size. This is a major advantage of the proposed structure for reducing its area delay product (ADP); particularly, when a large order ADF is implemented for higher block-sizes. ASIC synthesis result shows that, the proposed structure for filter length 64, has almost 14% and 30% less ADP and 25% and 37% less EPO than the best of the existing structures for block size 4 and 8, respectively. An advantage of this module is used to multiplier based technique and reduces power of the system but disadvantage of this module is large area and delay.

III. DISTRIBUTIVE ARITHMETIC TECHNIQUE

Distributed Arithmetic (DA) is a widely-used technique for implementing sum-of-products computations without the use of multipliers. Designers frequently use DA to build efficient Multiply-Accumulate Circuitry (MAC) for filters and other DSP applications. The main advantage of DA is its high computational efficiency. DA distributes multiply and accumulates operations across shifters; lookup tables (LUTs) and adders in such a way that conventional multipliers are not required.

Distributed arithmetic is an important algorithm for DSP applications. It is based on a bit level rearrangement of the multiply and accumulate operation to replace it with set of addition and shifting operations. The basic operations required are a sequence of table lookups, additions, subtractions and shifts of the input data sequence. The Look Up Table (LUT) stores all possible partial products over the filter coefficient space.

Assuming coefficients c[n] is known constants, and then y[n] can be rewritten as follows:

$$y[n] = \Sigma\, c[n] \cdot x[n] \quad n = 0, 1, \ldots, N\text{-}1 \tag{1}$$

Variable x[n] can be represented by:

$$x[n] = \Sigma\, x_b\,[n] \cdot 2^b \qquad b = 0, 1, \ldots, B\text{-}1$$

$$x_b[n] \in [0, 1] \tag{2}$$

Where $x_b[n]$ is the bth bit of x[n] and B is the input width. Finally, the inner product can be rewritten as follows:

$$y = \Sigma\ c[n]\ \Sigma\ x_b[k] \cdot 2^b \tag{3}$$

$$= c[0]\ (x_{B-1}[0]2^{B-1} + x_{B-2}[0]\ 2^{B-2} + \ldots + x_0[0]\ 2^0)$$

$$+ c[1]\ (x_{B-1}[1]\ 2^{B-1} + x\ x_{B-2}[1]\ 2^{B-2} + \ldots + x_0[1]\ 2^0) + \ldots$$

$$+ c[N-1]\ (x_{B-1}[N-1]\ 2^{B-1} + x_{B-2}[0]\ 2^{B-2} + \ldots + x_0[N-1]\ 2^0) \tag{4}$$

$$= (c[0]\ x_{B-1}[0] + c[1]\ x_{B-1} + \ldots + c[N-1]\ x_{B-1}[N-1])\ 2^{B-1} + (c[0]\ x_{B-2}[0]$$

$$+ c[1]\ x_{B-2}[1] + \ldots + c[N-1]\ x_{B-2}[N-1])\ 2^{B-2} + \ldots + (c[0]\ x_0[0] +$$

$$c[1]\ x_0[1] + \ldots + c[N-1]\ x_0[N-1])\ 2^0 \tag{5}$$

$$= \Sigma\ 2^b\ \Sigma\ c[n] \cdot x_b[k]$$

Where n=0, 1… N-1 and b=0, 1… B-1
The coefficients in most of DSP applications for the multiply accumulate operation are constants.

IV. PROPOSED METHODOLOGY

The above technique holds good only when we go for lower order filters. For higher order filters, the size of the LUT also increases exponentially with the order of the filter. For a filter with N coefficients, the LUT have 2N values. This in turn reduces the performance. it to block transpose form type-I configuration of block FIR filter. The DFG-3 can be retimed to obtain the DFG-4 of Figure 1, which is referred to block transpose form type-II configuration.
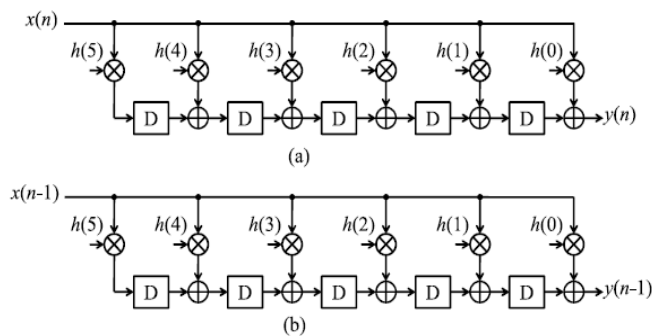

Figure 1: DFG of transpose form structure for *N* = 6. (a) DFG-1 for output *y(n)*. (b) DFG-2 for output *y(n − 1)*.
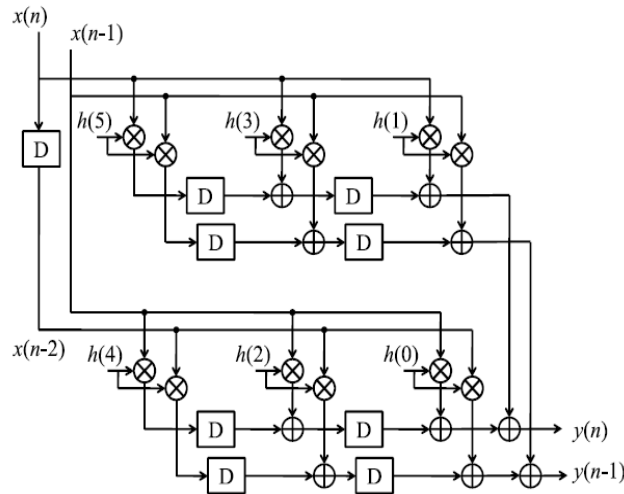
Figure 2: Merged DFG (DFG-3: transpose form type-I configuration for block FIR structure)
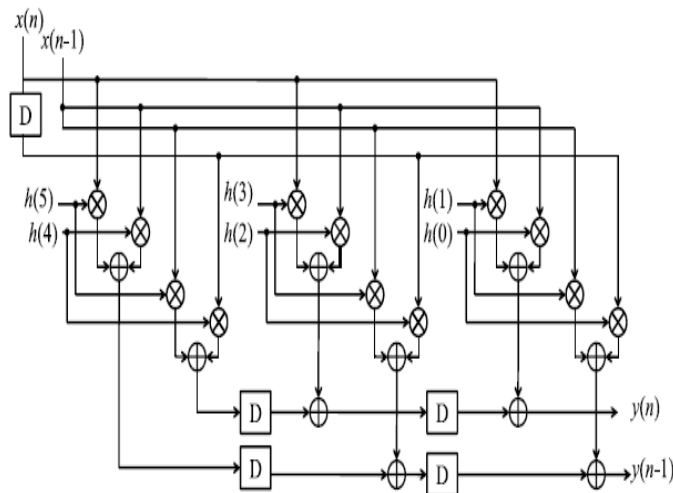

Figure 3: DFG-4 (retimed DFG-3) transpose form type-II configuration for block FIR structure

Note that both type-I and type-II configurations involve the same number of multipliers and adders, but type-II configuration involves nearly L times less delay elements than those of type-I configuration. We have, therefore, used block transpose form type-II configuration to derive the proposed structure. In Section II-C, we present mathematical formulation of block transpose form type-II FIR filter for a generalized formulation of the concept of block-based computation of transpose form FIR filers.
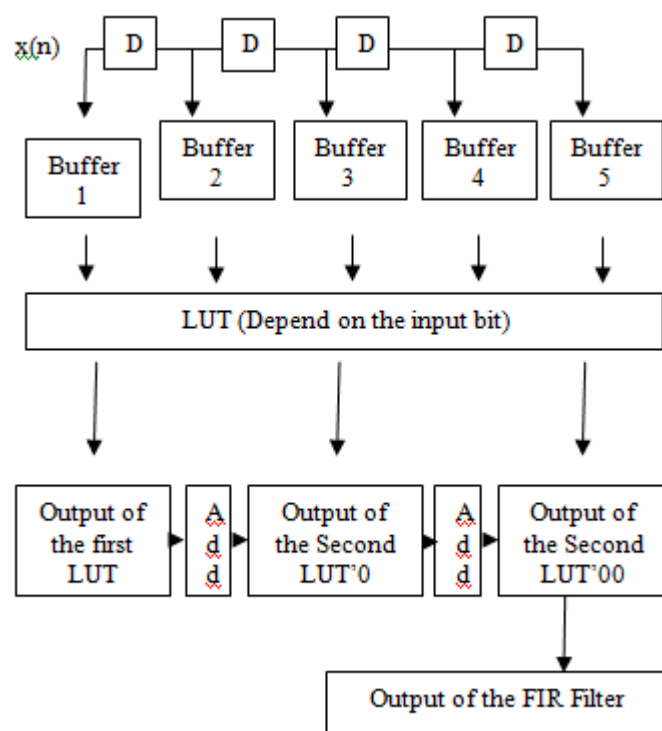
Figure 4: Block Diagram of Proposed Methodology

V. CONCLUSION

In this paper, we have explored the possibility of realization of block FIR filters in transpose form configuration for area delay efficient realization of both fixed and reconfigurable applications. A generalized block formulation is presented for transpose form block FIR filter, and based on that we have derived transpose form block filter for reconfigurable applications.

Finite Impulse Response filter plays an important role in many Digital Signal Processing applications. In this method, the multiplier less FIR filter is implemented using Distributed Arithmetic which consists of Look Up Table and then partitioning is involved. This architecture provides an efficient area-time power implementation which involves significantly less latency and less area-delay complexity when compared with existing structures for FIR Filter.

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