



## DESIGN OF MULTILEVEL TWO DIMENSIONAL-DISCRETE WAVELET TRANSFORM FOR IMAGE PROCESSING APPLICATIONS

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### ABSTRACT

The design of multilevel two dimensional-discrete wavelet transform (2D-DWT) with novel Vedic multiplier is presented. To design a 2D-DWT, digital finite impulse response (FIR) filter is used to increase the image resolution and eliminate the unwanted noise present in the image. Conventional three-level 2D-DWT is designed using regular Vedic multiplier. But it consumes more area and power. And also less image resolution. So multiplier-accumulate unit (MAC) unit in the FIR filter is changed to design the efficient FIR filter. Conventional FIR filter with regular Vedic multiplier is not working, when the carry input is 1. To overcome this fault, novel Vedic multiplier is proposed and designed using less half adder and full adder. The four level 2D-DWT is applied to increase the image resolution. Simulation is carried out using matrix laboratory (Matlab2008a) and Modelsim6.3c. Synthesis and Implementation is carried out using Xilinx and field programmable gate array (FPGA) Spartan3.

**Index Terms**— Two dimensional discrete wavelet transform (2D-DWT), Vedic multiplier, multiplier-accumulate unit (MAC), finite impulse response (FIR).

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### 1. INTRODUCTION

Multilevel two dimensional-discrete wavelet transform (2D-DWT) is used for digital signal processing (DSP) and image processing applications. Lifting based one dimensional- discrete wavelet transform (1D-DWT) provides less image resolution and processing time is also high. The wavelet transformation is an extensively used technique for image processing applications. Unlike traditional transforms such as the fast fourier transform (FFT) and discrete cosine transform (DCT), the discrete wavelet transform (DWT) holds both time and frequency data, based on a multi-resolution analysis technique. This is a powerful approach to signal processing and analysis. As its name implies, multi-resolution theory is concerned with the representation and analysis of signals or images at more than one resolution. This facilitates improved quality of reconstructed picture for the same

compression than is possible by other transforms. In order to implement the real time codec based on DWT, it needs to be targeted on a fast device. Field programmable gate array (FPGA) implementation of DWT results in higher processing speed and lower costs when compared to other implementations such as advanced RISC (reduced instruction set computer) machines (ARM) processors, DSPs etc. The Discrete wavelet transform is therefore increasingly used for image coding [4].

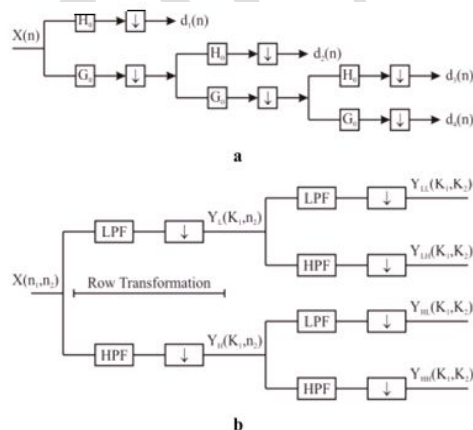
This is because the DWT can decompose the signals into different sub-bands with both time and frequency information and facilitate to arrive a high compression ratio. It supports features like progressive image transmission (by quality, by resolution), ease of compressed image manipulation, region of interest coding, etc. The joint photographic experts group (JPEG) 2000 incorporates the DWT

into its standard. Recently, several very large scale integration (VLSI) architectures have been proposed to realize single chip designs for DWT. Traditionally, such algorithms were implemented using programmable DSP chips for low-rate applications or VLSI application specific integrated circuits (ASICs) for higher rates. To perform the convolution, a fast multiplier is required, which is crucial in making the operations efficient [5].

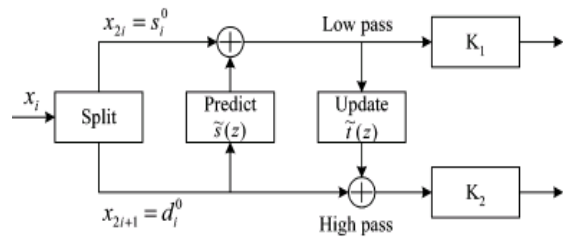
**2. LIFTING BASED DWT SCHEME**

The top level structural design for 1D-DWT is presented in Fig. 1a and Fig. 1b [10]. Input X is decomposed into several sub bands of low frequency and high frequency components to extract the detailed parameters from X using many stages of low pass filter (LPF) and high pass filters (HPF). The sub band filters are symmetric and satisfy orthogonal property. For an input image, the two 1D-DWT computations are carried out in the flat and perpendicular directions to compute the two level decomposition. The inverse DWT process combines the decomposed image sub bands to original signal [8].

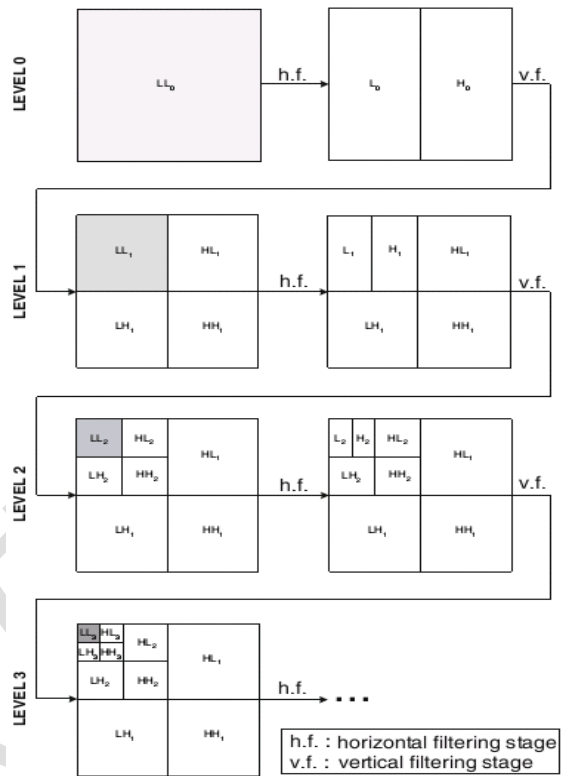
The reconstruction of image is possible, owing to the symmetric property and inverse property of low pass and high pass filter coefficients. Input  $x(n_1, n_2)$  is decomposed to four sub-components low-low ( $Y_{LL}$ ), low-high ( $Y_{LH}$ ), high-low ( $Y_{HL}$ ), high-high ( $Y_{HH}$ ). This results in a one level decomposition. The  $Y_{LL}$  sub-band component is further processed and is decomposed to another four sub-band components, thus forming two-level decomposition. This process is continued as per the design requirements till the requisite quality is obtained. Every stage of DWT requires LPF and HPF filters with down sampling by 2. Lifting based DWT computation is widely being adopted for image decomposition [2].



**Figure. 1. Image decomposition (a) one dimensional (b) two dimensional**



**Figure. 2. Lifting based forward one dimensional-discrete wavelet transform (1D-DWT)**



**Figure. 3. Dyadic decomposition for three decomposition levels**

In this work, a modified architecture based on Vedic multiplier is proposed to realize the lifting-based DWT. Lifting scheme is one of the techniques used to realize the DWT architecture.

Lifting scheme is used in order to reduce the number of operations to be performed by half, and filters can be decomposed into further steps in lifting scheme [7]. The memory required and also computation is less in the case of lifting scheme. The implementation of the algorithm is fast and inverse transform is also simple in this method. The block diagram for lifting scheme is shown in Fig. 2 [3].

First the input sequences  $x_i$  are split into even and odd parts,  $s_l^0$  and  $d_l^0$ . Next, the two lifting sequences are done by two lifting steps. The outputs are given by  $s_l^n$  and  $d_l^n$ , where  $n$  denotes the stage of lifting steps. Finally, through the normalization factors  $k_1$  and  $k_2$ , the low pass and the high filter coefficients  $s_i$

and  $d_i$  can be obtained.  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\delta$  are the constants.

1) Splitting step :

$$d_i^0 = x_{2i+1} \tag{1}$$

$$s_i^0 = x_{2i} \tag{2}$$

2) Lifting step :

(First lifting Step)

$$d_i^1 = d_i^0 + \alpha \times (s_i^0 + s_{i+1}^0) \quad \text{(predictor)} \tag{3}$$

$$s_i^1 = s_i^0 + \beta \times (d_{i-1}^1 + d_i^1) \quad \text{(updater)} \tag{4}$$

(Second Lifting Step)

$$d_i^2 = d_i^1 + \gamma \times (s_i^1 + s_{i+1}^1) \quad \text{(predictor)} \tag{5}$$

$$s_i^2 = s_i^1 + \delta \times (d_{i-1}^2 + d_i^2) \quad \text{(updater)} \tag{6}$$

3) Scaling step :

$$d_i = k_2 \times d_i^2 \tag{7}$$

$$s_i = k_1 \times s_i^2 \tag{8}$$

Because the 2D-DWT is a separable transform, it can be computed by applying the 1D-DWT along the rows and columns of the input image of each level during the horizontal and vertical filtering stages. Every time the 1D-DWT is applied on a signal, it decomposes that signal into two sets of coefficients, a low-frequency and a high-frequency set. The low frequency set is an approximation of the input signal at a coarser resolution, while the high-frequency set includes the details that will be used at a later stage during the reconstruction phase.

Dyadic decomposition for three decomposition levels is shown in Fig. 3 [11]. The input of level  $j$  is the low-frequency 2D sub band  $LL_j$ , which is actually the coarse image at the resolution of that level. In the first level, the image itself constitutes the  $LL$  image block ( $LL_0$ ). The coefficients  $L$  ( $H$ ), produced after the horizontal filtering at a given level, are vertically filtered to produce sub bands  $LL$  and  $LH$  ( $HL$  and  $HH$ ). The  $LL$  sub band will either be the input of the horizontal filtering stage of the next level, if there is one, or will be stored, if the current level is also the last one. All  $LH$ ,  $HL$  and  $HH$  sub bands are stored, to contribute later in the reconstruction of the original image from the  $LL$  sub band.

### 3. CONVENTIONAL VEDIC MULTIPLIER FOR MULTILEVEL 2D-DWT

Vedic mathematics is the name given to the ancient Indian system of mathematics that was rediscovered in the early twentieth century. Vedic

mathematics is based on sixteen principles or word-formulae which are termed as Sutras. A simple digital multiplier (referred henceforth as Vedic multiplier) architecture based on the Urdhva-Tiryakbhyam Sutra is proposed. The block diagram of conventional Vedic multiplier is shown in Fig. 4. Urdhva – Tiryakbhyam is the common formula applicable to all cases of multiplication and also in the division of a huge number by another huge number. It means perpendicularly and diagonally [1], [6], [12].

**Example1:** The product of 1111 and 1111 using Urdhva– Tiryakbhyam (vertically and crosswise) is given below,

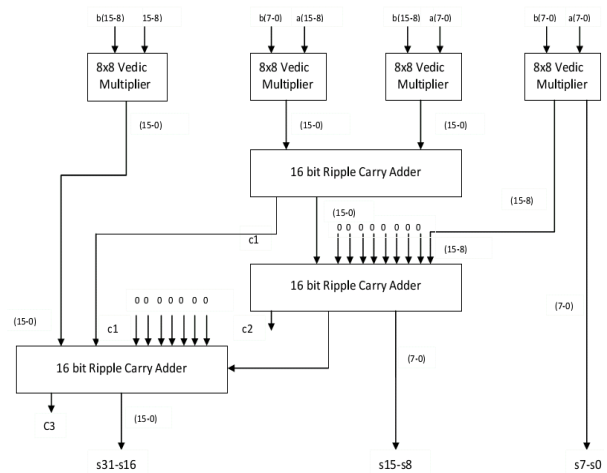
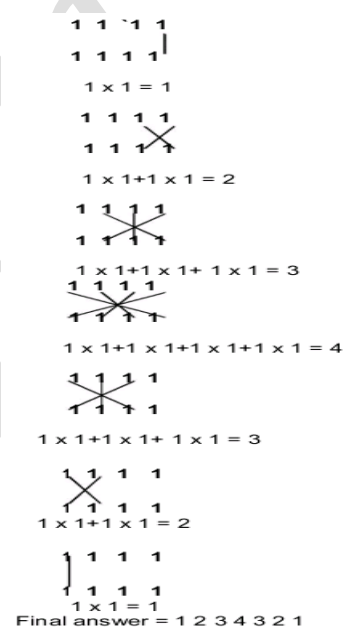


Figure. 4. Conventional Vedic multiplier

The 16x16 bit Vedic multiplier module is implemented using four 8x8 bit Vedic multiplier modules as shown in fig.4. To get the final product, four 8x8 bit Vedic multiplier and three 16-bit ripple-carry (RC) Adders are required.

#### 4. PROPOSED MULTILEVEL 2D-DWT WITH MODIFIED VEDIC MULTIPLIER

In general, the folded formation consists of a pair of 1D-DWT modules (row and column processor) and memory/storage component. The memory module consists of three forms, a frame memory, transposition memory, and temporal memory. Frame memory is necessary to store the low-low sub band for level-by-level computation of multilevel 2D-DWT. Transposition memory stores the intermediate values resulting from the row processor, and temporal memory is used by the column processor to store the partial results. Frame memory may either be on-chip or external, and the other two are on-chip memories. The block diagram of the proposed 2D-DWT architecture is shown in Fig. 5.

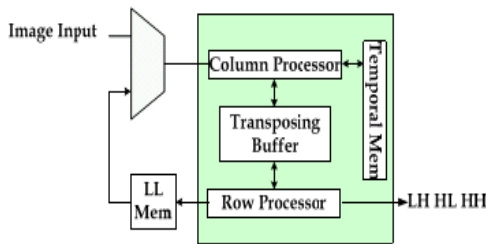


Figure 5. Block diagram of the proposed two dimensional-discrete wavelet transform (2D-DWT) architecture

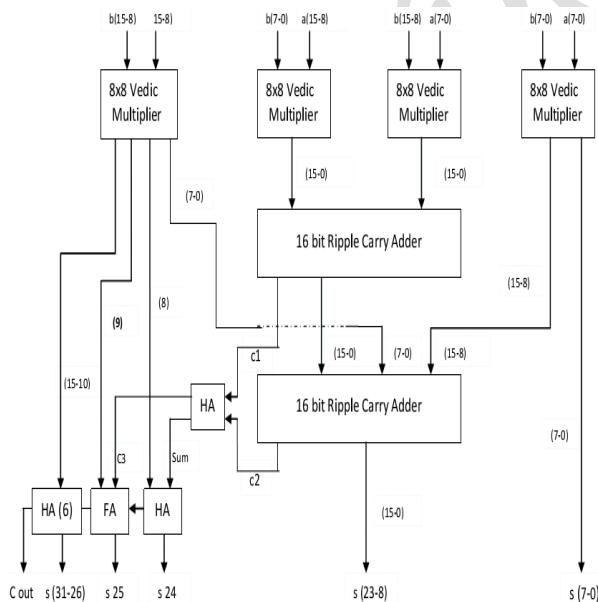


Figure 6. Block diagram of modified Vedic Multiplier

The beauty of Vedic mathematics lies in the fact that it reduces the otherwise cumbersome-looking calculations in conventional mathematics to a very easy one. This is due to the fact that the Vedic formulae are claimed to be based on the natural principles on which the human brain works. This is a

very essential field and provides some effective algorithms which can be applied to various branches of engineering such as computing and digital signal processing [12].

Firstly, the least significant bits (LSB) are multiplied which gives the LSB of the final product. Then, the LSB of the multiplicand is multiplied with the next higher bit of the multiplier and summed with the product of LSB of multiplier and the next higher bit of the multiplicand. The sum generates the second bit of the final product and the carry is added with the partial product obtained by multiplying the most significant bits to give the sum and carry. The sum is the third bit and carry becomes the fourth bit of the final product.

The 16x16 bit Vedic multiplier module is implemented using four 8x8 bit Vedic multiplier modules as shown in Fig. 6. Let's analyze 16x16 multiplications, say  $A = A_{15} A_{14} A_{13} A_{12} A_{11} A_{10} A_9 A_8 A_7 A_6 A_5 A_4 A_3 A_2 A_1 A_0$  and  $B = B_{15} B_{14} B_{13} B_{12} B_{11} B_{10} B_9 B_8 B_7 B_6 B_5 B_4 B_3 B_2 B_1 B_0$ . The output for the multiplication result is  $S_{31} S_{30} S_{29} S_{28} S_{27} S_{26} S_{25} S_{24} S_{23} S_{22} S_{21} S_{20} S_{19} S_{18} S_{17} S_{16} S_{15} S_{14} S_{13} S_{12} S_{11} S_{10} S_9 S_8 S_7 S_6 S_5 S_4 S_3 S_2 S_1 S_0$ . Let's divide A and B into two parts, say the 16 bit multiplicand A can be decomposed into pair of 8 bits  $A_H A_L$ . Similarly multiplicand B can be decomposed into  $B_H B_L$ .

Each block as shown is 8x8 bit Vedic multiplier. First 8x8 bit multiplier inputs are  $A_7 A_6 A_5 A_4 A_3 A_2 A_1 A_0$  and  $B_7 B_6 B_5 B_4 B_3 B_2 B_1 B_0$ . The last block is 2x2 bit multiplier with inputs  $A_{15} A_{14} A_{13} A_{12} A_{11} A_{10} A_9 A_8$  and  $B_{15} B_{14} B_{13} B_{12} B_{11} B_{10} B_9 B_8$ . The middle one shows two 8x8 bit multiplier with inputs  $A_{15} A_{14} A_{13} A_{12} A_{11} A_{10} A_9 A_8$  &  $B_7 B_6 B_5 B_4 B_3 B_2 B_1 B_0$  and  $A_7 A_6 A_5 A_4 A_3 A_2 A_1 A_0$  &  $B_{15} B_{14} B_{13} B_{12} B_{11} B_{10} B_9 B_8$ . So the final result of multiplication, which is of 32 bit,  $S_{31} S_{30} S_{29} S_{28} S_{27} S_{26} S_{25} S_{24} S_{23} S_{22} S_{21} S_{20} S_{19} S_{18} S_{17} S_{16} S_{15} S_{14} S_{13} S_{12} S_{11} S_{10} S_9 S_8 S_7 S_6 S_5 S_4 S_3 S_2 S_1 S_0$ . To get the final product ( $S_{31} S_{30} S_{29} S_{28} S_{27} S_{26} S_{25} S_{24} S_{23} S_{22} S_{21} S_{20} S_{19} S_{18} S_{17} S_{16} S_{15} S_{14} S_{13} S_{12} S_{11} S_{10} S_9 S_8 S_7 S_6 S_5 S_4 S_3 S_2 S_1 S_0$ ), four 8x8 bit Vedic multipliers, eight half adders, one full adder and two 16-bit Ripple-Carry (RC) Adders are required.

The modified Vedic multiplier is proposed to reduce the total number of half adder and full adder and rectify the fault, when the carry input is 1. The four-level, 2D-DWT is applied to increase the image resolution than the conventional three-level 2D-DWT and is shown in Fig. 7.



### 5. RESULTS AND DISCUSSIONS

Conventional Vedic multiplier, shows the result in wrong, when 15X11, it gives 105, instead of 165 due to carry output 1 is not processed. To overcome this fault, modified Vedic multiplier is proposed. Simulation is done using Modelsim6.3c. Simulation result of conventional Vedic multiplier is shown in Fig. 8.

Modified Vedic multiplier as shown in Fig. 6. is used to give the exact result, when the carry input is 1. Instead of 16bit ripple carry adders (32 half adder), 8 half adders and one full adder is used in the modified Vedic multiplier to reduce the area and delay than the conventional Vedic multiplier. Simulation result of modified Vedic multiplier is shown in Fig. 9. Performance analysis of conventional and modified MAC Unit for 2D-DWT is shown in Fig. 10.

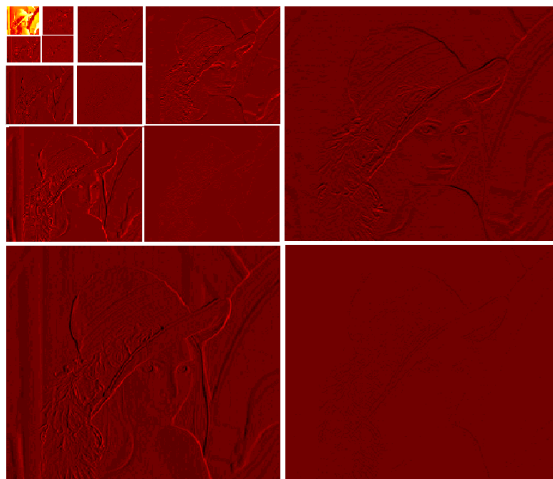


Figure. 7. Image decomposition output of four level two dimensional-discrete wavelet transform (2D-DWT)

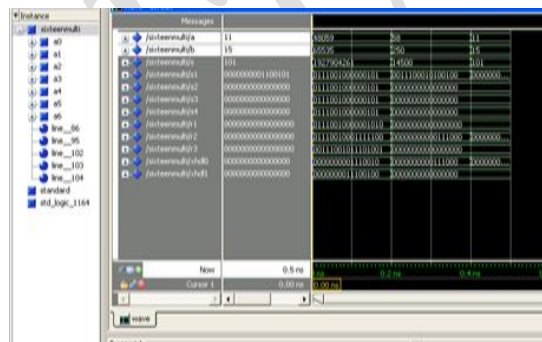


Figure. 8. Simulation result of Conventional Vedic multiplier with fault during carry=1

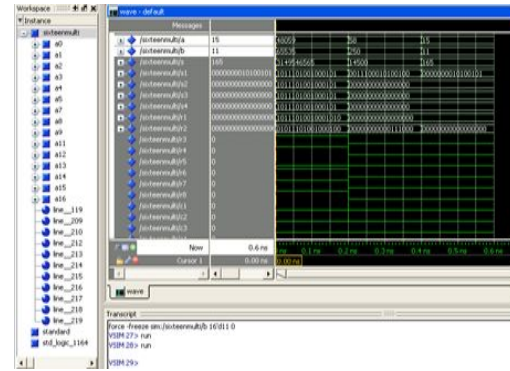


Figure. 9. Simulation result of proposed Vedic multiplier without fault during carry=1

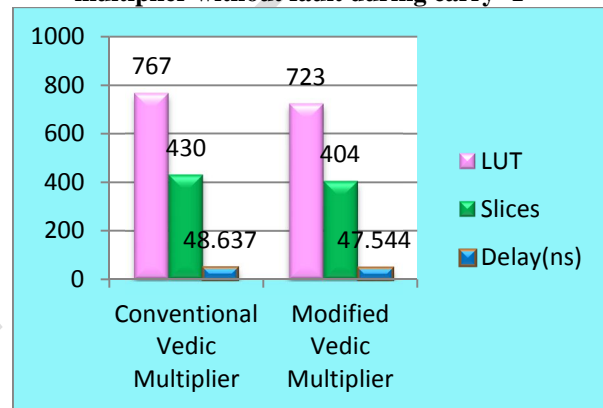


Figure. 10. Performance analysis of Conventional and modified multiplier-accumulate (MAC) Unit for two dimensional-discrete wavelet transform (2D-DWT)

### 6. CONCLUSION

An efficient multiplier called modified Vedic multiplier has been proposed for multilevel 2D-DWT. The proposed multiplier provides low area and less delay by use of less number of full adders and half adders instead of ripple carry adder. In this paper, hardware design and implementation of FPGA based parallel architecture for 2D-DWT with modified Vedic multipliers is presented. The design was implemented on Xilinx Spartan 3 XC3S50 FPGA device. Comparative study of the multilevel 2D-DWT with regular Vedic multiplier and modified Vedic multiplier was done. The Modified Vedic multiplier as compared to regular Vedic multiplier shows much more reduction in device utilization. The proposed method offers 20% area and 10% power reduction than the existing architecture. Hence it is concluded that, the modified Vedic multiplier based on multilevel 2D-DWT provides an efficient method for reducing the area and delay of MAC unit of the FIR filter for 2D-DWT.

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