Implementation of Vedic Complex Multiplier for Digital Signal Processing

Ms. Rajashri K. Bhongade, Ms. Sharada G. Mungale, Mrs. Karuna Bogawar

Abstract—
Basic and heart of all DSP are its multiplier. Speed of multiplier determines the speed of the DSP. In DSP fast multiplication is very important for convolution, Fourier transforms, and Multiplication is the most basic operation with deep and thorough arithmetic computation. Latency and throughput are two important parameters associated with multiplication performed in DSP.

In this paper VHDL implementation of complex number multiplier using ancient Vedic mathematics. By using “Vedic Mathematics” concept can skip carry propagation delay. The “Urdhva Tiryakbhyam” sutra was selected for implementation since it is applicable to all cases of multiplication. Meaning of “Urdhva Tiryakbhyam” is vertically and crosswise. The partial product and sum are generated in single step which reduce carry propagation from LSB to MSB. The main feature of proposed system is flexibility. The important feature of this project is to improve the speed of complex multiplier using Vedic mathematics. The implementation of Vedic mathematics and their application to complex multiplier ensure reduction of propagation delay. The proposed system is designed using VHDL and is implemented through Xilinx ISE 9.1i navigator series. The combinational delay obtained after the synthesis is compared with Booth’s complex multiplier. Vedic complex multiplier can bring great improvement in the DSP performance.

Keywords—Vedic multiplier, Urdhva tiryakbhyam, VHDL, DSP.

1. INTRODUCTION

Multiplier is an important component of many high performance systems such as FIR filters, microprocessor, digital signal processor, etc. Complex number multiplication is important in Digital single processing (DSP), specially in DIT-FFT twiddle factor multiplied with input is complex number. Image processing (IP). To implement Discrete Fourier Transform (DFT), Discrete Cosine Transform (DCT), Fast Fourier Transform (FFT) and wireless communication imaging, complex multiplier are essential. Complex numbers mostly depend on extensive number of multiplication. Four real number multiplication and two additions or subtractions are involved in complex number multiplication. Multiplication is done by AND operation & addition is done by OR operation. Carry needs to be propagated from the least significant bit (LSB) to the most significant bit (MSB) when binary partial products are added in real number multiplication. Competence of multiplier is based on variation of speed, area and configuration. After binary multiplication, the overall speed is drop down by addition and subtraction [4][5].

Vedic mathematics is extracted from four Vedas, which is an upya-veda of Atharva-veda. Vedic Mathematics is based on 16-sutras and 16-sub sutras invented in (1884-1960). In Vedic mathematics, there are sutras Nikhilam Navatasca Manas Dasatah and Urdhva Tiryakbhyam used for multiplication[1]. Our targeted Vedic sutra (algorithm) which is suitable for all cases of multiplication is Urdhva Tiryakbhyam.

Multiplication is one of the basic hardwared blocks in complex multiplier used in most digital signal processing systems. With advances in technology, many researchers have tried to design multipliers which offer high speed and low power consumption.

In this paper high speed complex multiplier is designed using Vedic mathematics. In this work, we try to present complex multiplication operations and the implementation of these using both booth’s as well as Vedic mathematical methods in VHDL language [1]. We highlight a comparative study of both approaches in terms of gate delays.

II. THE VEDIC MULTIPLICATION METHOD

The Vedic Mathematics is an ancient mathematic invented by Jagadguru Shankaracharya...
Bharati Krishna Teerthaji Maharaja. Vedic mathematic is based on 16 sutra and 16 sub-sutra. These sutra have been traditionally used for multiplication of two numbers. The proposed complex number multiplier is based on the Urdhva Tiryakbhyam sutra. In this work the same ideas are applied to binary number system as well as decimal number system, to make the proposed algorithm compatible with the digital hardware.

Vedic multiplication based on Urdhva Tiryakbhyam sutra is discussed below

A. Urdhva Tiryakbhyam sutra

The basic meaning of Sanskrit word is “Vertically and crosswise”. It is applicable to all multiplication. The vertical and crosswise multiplication can be implemented starting either from left hand side or from right hand side [7][8]. Significance of vertically is straight above multiplication and significance of crosswise is diagonal multiplication and add them. In “Urdhva Tiryakbhyam sutra” multiplication is done in single line manner, implies the increase in speed by reducing propagation delay [9][12]. This sutra traditionally used for multiplication of decimal numbers. In this paper same ideas apply for binary number system.

It literally means “Vertically and crosswise”. It is based on a novel concept through which the generation of all partial products can be done with the concurrent addition of these partial products. Since the partial products and their sums are calculated in parallel. To calculate the product the multiplier is independent of the clock frequency of the processor. Thus the multiplier will require the same amount of time and hence is independent of the clock frequency. The Multiplier has the advantage that as the number of bits increases, gate delay and area increases very slowly as compared to other multipliers. Therefore it is time, space and power efficient

“Urdhva Tiryakbhyam sutra” to binary number system knowledge that multiplication of two bit is done by AND operation and it is implemented by using AND operation. General multiplication procedure using “Urdhva Tiryakbhyam sutra” is illustrated below.

The below figure shows multiplication of (4x4) bit number, performance is starting from right hand side. Corresponding expression as follows:

![Figure 1: Line diagram for multiplication of two 4-bit numbers.](image)

Firstly, least significant bits are multiplied which gives the least significant bit of the product (vertical). Then, the LSB of the multiplicand is multiplied with the next higher bit of the multiplier and added with the product of LSB of multiplicand and next higher bit of the multiplicand (crosswise). The sum gives second bit of the product and the carry is added in the output of next stage sum obtained by the crosswise and vertical multiplication and addition of three bits of the two numbers from least significant position. Next, all the four bits are processed with crosswise multiplication and addition to give the sum and carry. The sum is the corresponding bit of the product and the carry is again added to the next stage multiplication and addition of three bits except the LSB. The same operation continues until the multiplication of the two MSBs to give the MSB of the product.

Thus we get the following expressions:

\[ r_0 = a_0 b_0 \]
\[ c_{11} = a_1 b_0 + a_0 b_1 \]
\[ c_{2r_2} = c_1 + a_2 b_0 + a_1 b_1 + \] \[ a_0 b_2 \]
\[ c_{3r_3} = c_2 + a_3 b_0 + a_2 b_1 + \] \[ a_1 b_2 + a_0 b_3 \]
\[ c_{4e_4} = c_3 + a_4 b_1 + a_2 b_2 + \] \[ a_1 b_3 \]
\[ c_{5r_5} = c_4 + a_5 b_2 + a_2 b_3 \]
\[ c_{6r_6} = c_5 + a_3 b_3 \]

With \( c_{6r_6} r_5 r_4 r_3 r_2 r_1 r_0 \) being the final product [3] [4] [8].

The Hardware architecture realization of multiplier of Urdhva Tiryakbham shown in figure 2. All the partial product are calculated parallel and delay is
associated to time taken by carry to propagate through adder.

**III. COMPLEX MULTIPLIER**

Complex number consists of two component called Real part (R) and Imaginary part (I).

For implementing complex number multiplication, require real part and imaginary part.

\[ R + j I = (a + j b)(c + j d) \]  

(1)

(a + j b) is first complex number,  
(c + j d) is second complex number,

From equation(1) gives two separate final result to calculate real and imaginary part. The real part of the output can be computed using (ac-bd), and the imaginary part of the result can be computed using (bc+ad). Thus four separate multiplications and addition/subtraction are required to produce the real as well as imaginary part numbers [9] [10] Multiplication is performed by using “Urdhva Tiryakabhyaam sutra”.

Complex Multiplication Algorithm : \((a+jb)\ (c+jd) = R+jI\)

**<Input>:**

A and B:

\((a+jb)\) and \((c+jd)\) both are complex number.  
\((a+jb)\) and \((c+jd)\) both are inputs.

Real part of A = a; 
Imaginary part of A = b; 
Real part of B = c; 
Imaginary part of B = d;

**<Output>:**

Result: R and I are the real and imaginary part of complex number.

**Figure 4:** Proposed methodology for complex number multiplication

**IV. DESIGN & IMPLEMENTATION**

The Vedic Complex Multiplier is implemented using VHDL and also other multipliers like booth multiplier are also implemented. The entire code is completely synthesizable. The synthesis is done using Xilinx Synthesis Tool (XST) available with Xilinx ISE 9.1i simulator. The design is optimized for speed and area using Xilinx.

Table 1 indicate the area consumed and speed taken to do the implementation for 4-bit Vedic complex & Booth complex multipliers. Table 2 indicate the area consumed and speed taken to do the implementation for 4-bit & 8-bit Vedic complex. While Figure 6 & 7 indicates the RTL schematic of the 4 bit Vedic complex multiplier and Booth’s complex multiplier. Figure 8 & 9 indicates the simulation waveform for 4-bit Vedic complex multiplier and Booth’s complex multiplier.

The speed taken to do the implementation for 4-bit Vedic complex, Booth complex multipliers are given in below Charts(Figure 5).
TABLE 1: DEVICE UTILIZATION SUMMARY

<table>
<thead>
<tr>
<th>Algorithm(4bit)</th>
<th>NO. of Slices</th>
<th>NO. of 4 input Slices</th>
<th>NO. Of IO’s</th>
<th>Delay in ns.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vedic complex</td>
<td>84</td>
<td>147</td>
<td>33</td>
<td>18.41</td>
</tr>
<tr>
<td>Booth’s complex</td>
<td>100</td>
<td>174</td>
<td>33</td>
<td>19.66</td>
</tr>
</tbody>
</table>

![Figure 5: Comparison of 4 bit Multipliers with respect to delay](image)

![Figure 6: RTL schematic of Vedic complex multiplier.](image)

![Figure 7: RTL schematic of Booth’s complex multiplier.](image)

![Figure 8: Simulation waveforms for 4-bit complex multiplication (Vedic).](image)

![Figure 9: Simulation waveforms for 4-bit complex multiplication (Booth’s).](image)

![Figure 10: Simulation waveforms for 8-bit complex multiplication (Vedic).](image)

TABLE II: DEVICE UTILIZATION SUMMARY

<table>
<thead>
<tr>
<th>Vedic Complex Multiplier</th>
<th>NO. of Slices</th>
<th>NO. of 4 input Slices</th>
<th>NO. Of IO’s</th>
<th>Delay in ns.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4x4</td>
<td>84</td>
<td>147</td>
<td>33</td>
<td>18.41</td>
</tr>
<tr>
<td>8x8</td>
<td>385</td>
<td>674</td>
<td>64</td>
<td>30.90</td>
</tr>
</tbody>
</table>

V. EXPERIMENTAL RESULTS

The work presented in this paper was implemented using VHDL and logic simulation was done using Xilinx ISE simulator and synthesis was done using Xilinx project navigator. The design was synthesized for Spartan3 (xc3s200-5-ft256) device. The obtained results are presented in table 1, and waveforms for 4-bit complex multiplication using Urdhva Tiryabhyam and Booth’s algorithm is shown in figure 8 & 9 respectively. The device utilization in case of Vedic complex is less (No. of Slics: 84 out of 1920 - 4%, Number of 4 input LUTs: 147 out of 3840 - 3%, Number of bonded IOBs: 33 out of 173 - 19%) compared to Booth’s complex (No. of Slices: 100 out of 1920 - 5%, Number of 4 input LUTs: 174 out of 3840 - 4%, Number of bonded IOBs: 33 out of 173 - 19%). The delay required by Vedic complex multiplier is 18.41 ns, while it is 19.66 ns for Booth’s complex. The device utilization in case of Vedic complex is less (No. of Slices: 385 out of 1920 - 20%, Number of 4
input LUTs: 674 out of 3840 - 17%, Number of bonded IOBs: 66 out of 173 - 36%)
Vedic complex multiplier has the greatest advantage as compared to other complex multipliers over gate delays and regularity of structures. The results also suggest that Vedic complex multiplier is faster than other complex multipliers and thus this is extremely advantageous.

VI. CONCLUSION
Vedic Mathematics gives us a clue of symmetric computation. Vedic mathematics deals with various topics of mathematics such as basic arithmetic, geometry, trigonometry, calculus etc. All these methods are very efficient as far as manual calculations are concerned. The proposed Vedic complex multiplier proves to be highly efficient in terms of the speed. The main advantage is delay increases slowly as the input bits increases. Most of the important DSP algorithms, such as convolution, discrete Fourier transforms, fast Fourier transforms, digital filters. Since the multiplication time is generally far greater than the addition time, the total processing time for any DSP algorithm primarily depends upon the number of multiplications. Hence, this multiplier can be used to implement the above DSP algorithms.

ACKNOWLEDGMENT
I Ms. Rajashri K. Bhongade seize this opportunity to thank all the people who directly or indirectly helped me in completion of my project. I take immense pride in paying gratitude to my project guide Prof. Ms. Sharada Mungale, Prof. Mrs. Karuna Bogawar, who always appreciated me for innovative ideas and given me a chance to implement them.

REFERENCES