

An Efficient Implementation of High Speed Low Power Vedic Multipliers Using Reversible Gates

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Abstract: *Multiplier design is always a challenging task; how many ever novel designs are proposed, the user needs demands much more optimized ones. Vedic mathematics is world renowned for its algorithms that yield quicker results, be it for mental calculations or hardware design. Power dissipation is drastically reduced by the use of Reversible logic. The reversible Urdhva Tiryakbhayam Vedic multiplier is one such multiplier which is effective both in terms of speed and power. In this paper we aim to enhance the performance of the previous design. The Total Reversible Logic Implementation Cost (TRLIC) is used as an aid to evaluate the proposed design. This multiplier can be efficiently adopted in designing Fast Fourier Transforms (FFTs) Filters and other applications of DSP like imaging, software defined radios, wireless communications.*

Keywords— *Quantum Computing, Reversible Logic Gate, Urdhva Tiryakbhayam, Optimized Design, TRLIC.*

INTRODUCTION

Vedic Mathematics is one of the most ancient methodologies used by the Aryans in order to perform mathematical calculations [2]. This consists of algorithms that can boil down large arithmetic operations to simple mind calculations. The above said

advantage stems from the fact that Vedic mathematics approach is totally different and considered very close to the way a human mind works. The efforts put by Jagadguru Swami Sri Bharati Krishna Tirtha Maharaja to introduce Vedic Mathematics to the commoners as well as streamline Vedic Algorithms into 16 categories [1] or Sutras needs to be acknowledged and appreciated.

The Urdhva Tiryakbhayam is one such multiplication algorithm which is well known for its efficiency in reducing the calculations involved. With the advancement in the VLSI technology, there is an ever increasing quench for portable and embedded Digital Signal Processing (DSP) systems. DSP is omnipresent in almost every engineering discipline. The paper is organized as follows:

The section II gives the basics of reversible logic along with the literature review. Section III explains the Urdhva Tiryakbhayam algorithm. The section IV describes the modifications of the previous design in order to evolve the optimized design. Section V compares the proposed design with the other non Vedic multipliers as well as the previous Vedic multiplier design and draws a conclusion claiming the versatility of Reversible Urdhva Tiryakbhayam multiplier.

REVERSIBLE LOGIC

A. Literature Survey and Significance of reversible logic Conventional combinational logic circuits are known to dissipate heat for every bit of information that is lost. This is also evident from the second law of thermodynamics which states that any irreversible process leads to loss of energy.

Landauer [3] showed that any gate that is irreversible, necessarily dissipates energy, and each irreversible bit generates $k \cdot T \ln 2$ joules of heat where k is Boltzmann's constant (1.38×10^{-23} joules/Kelvin) and T is temperature in Kelvin. Lowering the threshold voltage and management of the power supply are widely applied practices to decrease the energy consumption in any logical operation [23].

However these technologies of lowering the energy consumption will hit a barrier of kT [24]. In order to alleviate this, techniques such as reducing the temperature of computer and constructing a thermodynamically reversible computer can be used [25].

REVERSIBLE LOGIC GATES

Reversible computing is a model of computing where the computational process to some extent is reversible, i.e., time-invertible. In a computational model that uses transitions from one state of the abstract machine to another, a necessary condition for reversibility is that the relation of the mapping from states to their successors must be one-to-one. Reversible computing is generally considered an unconventional form of computing.

A Reversible Logic gate is an n -input n -output logic function in which there is a one-to-one correspondence between the inputs and the outputs. This not only helps to determine the outputs from the inputs but also the inputs can be uniquely recovered from the outputs. Because of this bijective mapping the output vectors are merely permutations of the input vectors.

Some of the basic reversible logic gates in the literature those are useful in designing the Reversible

Urdhva Tiryakbhayam Multiplier are shown in the figure.

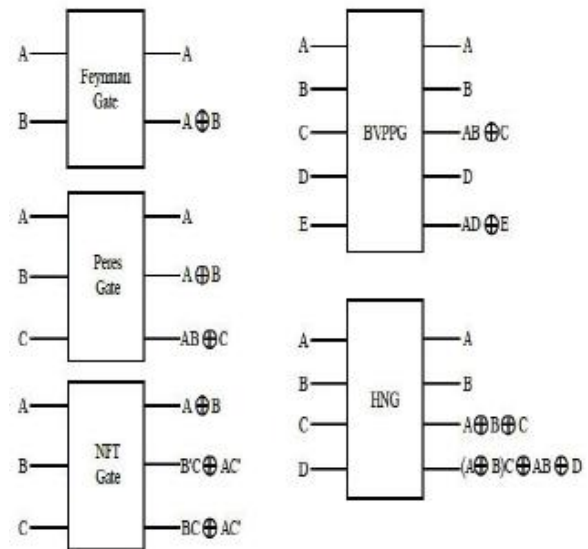


Figure: reversible logic gates

Optimization parameters for reversible logic circuits:

The important parameters which play a major role in the design of an optimized reversible logic circuit are as listed:

- **Constants (CI):** This refers to the number of inputs that are to be maintained constant at either 0 or 1 in order to synthesize the given logical function.
- **Garbage (GO):** This refers to the number of outputs which are not used in the synthesis of a given function. These are very essential, without which reversibility cannot be achieved.
- **Gate count (NG):** The number of reversible gates used to realize the function.
- **Flexibility:** This refers to the universality of a reversible logic gate in realizing more functions.
- **Quantum cost (QC):** This refers to the cost of the circuit in terms of the cost of a primitive gate. It is

calculated knowing the number of primitive reversible logic gates (1x1 or 2x2) required to realize the circuit

- Gate levels: This refers to the number of levels in the circuit which are required to realize the given logic functions.

- Total Reversible Logic Implementation Cost (TRLIC) [12]: Let, in a reversible logic circuit there are NG reversible logic gates, CI constant inputs, GO number of garbage outputs, and have a quantum cost QC. Then the TRLIC is given as

$$TRLIC = \sum(NG + CI + GO + QC) \dots 1$$

URDHVA TIRYAKBHAYAM MULTIPLICATION ALGORITHM

Urdhva Tiryakbhayam (UT) is a multiplier based on Vedic mathematical algorithms devised by ancient Indian Vedic mathematicians. Urdhva Tiryakbhayam sutra can be applied to all cases of multiplications viz. Binary, Hex and also Decimals. It is based on the concept that generation of all partial products can be done and then concurrent addition of these partial products is performed. The parallelism in generation of partial products and their summation is obtained using Urdhva Tiryakbhayam.

Unlike other multipliers with the increase in the number of bits of multiplicand and/or multiplier the time delay in computation of the product does not increase proportionately. Because of this fact the time of computation is independent of clock frequency of the processor.

Hence one can limit the clock frequency to a lower value. Also, since processors using lower clock frequency dissipate lower energy, it is economical in terms of power factor to use low frequency processors employing fast algorithms like the above mentioned. The Multiplier based on this sutra has the advantage that as the number of bits increases, gate delay and area increases at a slow pace as compared to other conventional multipliers.

The Algorithm: Multiplication of 101 by 110.

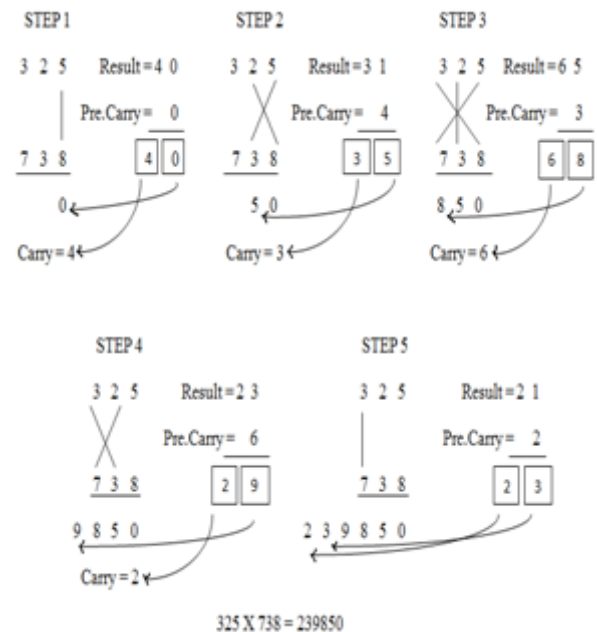


Figure: urdhva tiryakbhayam procedure for multiplication

1. We will take the right-hand digits and multiply them together. This will give us LSB digit of the answer.
2. Multiply LSB digit of the top number by the second bit of the bottom number and the LSB of the bottom number by the second bit of the top number. Once we have those values, add them together.
3. Multiply the LSB digit of bottom number with the MSB digit of the top one, LSB digit of top number with the MSB digit of bottom and then multiply the second bit of both, and then add them all together.
4. This step is similar to the second step, just move one place to the left. We will multiply the second digit of one number by the MSB of the other number.
5. Finally, simply multiply the LSB of both numbers together to get the final product.

OPTIMIZATION OF THE URDHVA TIRYAKBHAYAM MULTIPLIER

The conventional logic design implementation of a 2x2 Urdhva Tiryakbhayam multiplier using the irreversible logic gates [8] is shown in the Figure 3. In [12] the four expressions for the output bits are derived from

this figure and are used to obtain the reversible implementation as shown in Figure 4. The circuit uses five Peres gates and one Feynman gate. This design has a total quantum cost of 21, number of garbage outputs as 11 and number of constant inputs 4. The gate count is 6. This design does not take into consideration the fan outs. The overall performance of the UT multiplier is scaled up by optimizing each individual unit in terms of quantum cost, garbage outputs etc.

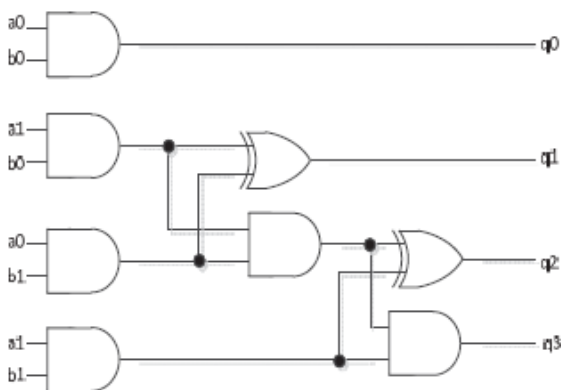


Figure: conventional 2x2 urdhva tiryakbhayam multiplier

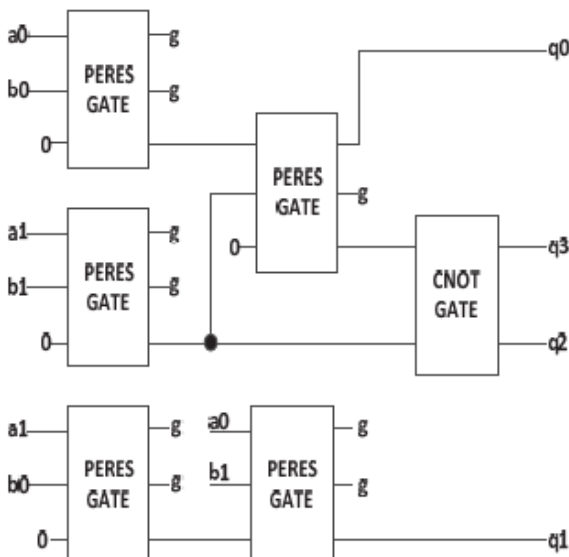


Figure: Reversible 2x2 UT multiplier

Design of 4x4 Urdhva Tiryakbhayam Reversible multiplier:

The Reversible 4X4 Urdhva Tiryakbhayam Multiplier design emanates from the 2X2 multiplier. The block

diagram of the 4X4 Vedic Multiplier is presented in the figure 6. It consists of four 2X2 multipliers each of which procures four bits as inputs; two bits from the multiplicand and two bits from the multiplier. The lower two bits of the output of the first 2X2 multiplier are entrapped as the lowest two bits of the final result of multiplication. Two zeros are concatenated with the upper two bits and given as input to the four bit ripple carry adder. The other four input bits for the ripple carry adder are obtained from the second 2X2 multiplier. Likewise the outputs of the third and the terminal 2X2 multipliers are given as inputs to the second four bit ripple carry adder. The outputs of these four bit ripple carry adders are in turn 5 bits each which need to be summed up. This is done by a five bit ripple carry adder which generates a six bit output. These six bits can form the upper bits of the final result.

Modification in the design of ripple carry adder:

The design shown in [12] consists of only HNG gates. The number of HNG gates is 4 if the ripple carry adder is used in the second stage or five if the ripple carry adder is used in the last stage of the 4X4 Urdhva Tiryakbhayam Multiplier. The ripple carry adder can be modified as under. Since for any ripple carry adder the input carry for the first full adder is zero, this implicitly means the first adder is a half adder. Thus a Peres gate can efficiently replace a HNG. This cut down the quantum cost by two for any ripple carry adder and the garbage output by one. The Constant inputs and the gate count remain unchanged.

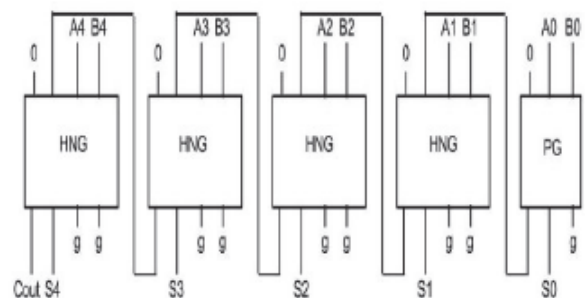


Figure: proposed modified 5 bit ripple carry adder design

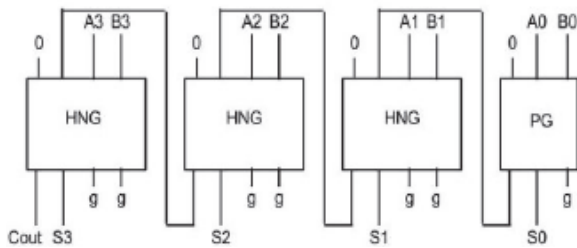


Figure: proposed modified 4 bit ripple carry adder design

4X4 Reversible multiplier:

The design of the reversible 2x2, 4x4 and 8x8 multipliers using reversible logic gates are logically verified using XILINX 14.2. The following are the important design constraints for any reversible logic circuits.

1. Reversible logic circuits should have minimum quantum cost.
2. The design can be optimized so as to produce minimum number of garbage outputs.
3. The reversible logic circuits must use minimum number of constant inputs.
4. The reversible logic circuits must use a minimum number of reversible gates.

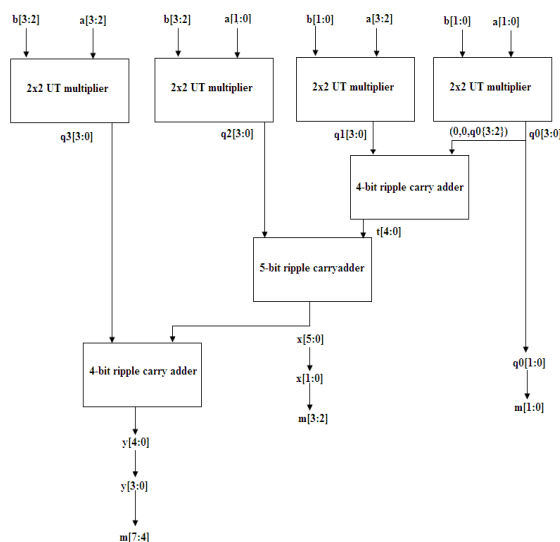


Figure: 4X4 UT Multiplier

IMPLEMENTATION OF 8X8 BIT REVERSIBLE VEDIC MULTIPLIER

The block diagram of the 8x8 Vedic Multiplier is presented in the figure3.1. It consists of four 2X2

multipliers each of which procedures 16 bits as inputs; 8 bits from the multiplicand and 8 bits from the multiplier. The output of the first 4x4 multiplier are entrapped as the lowest four bits of the final result of multiplication. The second 4x4 multiplier output and third 4x4 multiplier are given as input to the ripple carry bit 8 adder. The output from the 8-bit carry adder along with the four zeros are concatenated upper four bits of the output of the first 4X4 multiplier are given as input to the nine bit ripple carry adder. The upper four bits are entrapped as the middle bits in the final result. The upper bit output of the nine bit ripple carry adder concatenated with two zeroes along with the fourth output of 4x4 multiplier gives the final higher output bits. These bits can form the upper bits of the final result.

The ripple carry adder is consummated (realized) using the HNG Gate. The number of bits that need to be ripple carried verdicts the number of HNG gates to be used. Thus a 8 bit ripple carry adder needs 8 HNG gates and the 9 bit adder requires 9 HNG gates. This design also does not take into consideration the fan out gates. Here "a" and "b" are two numbers to be multiplied and "y" is the product. With this design we are now ready to code this in verilog easily using reversible gates. To make the design more modular we write code for gates first and then instantiate it to have the final product.

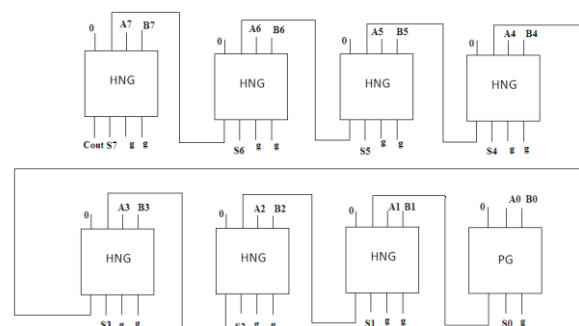


Figure: 8-bit ripple carry adder

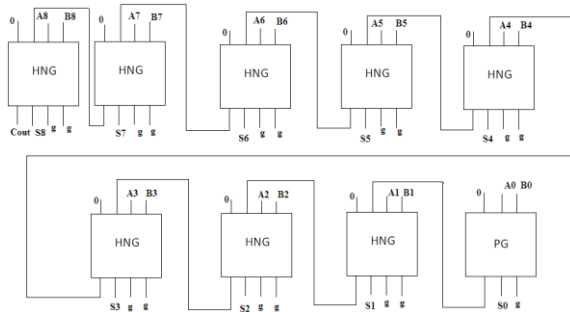


Figure: 9-bit ripple carry adder

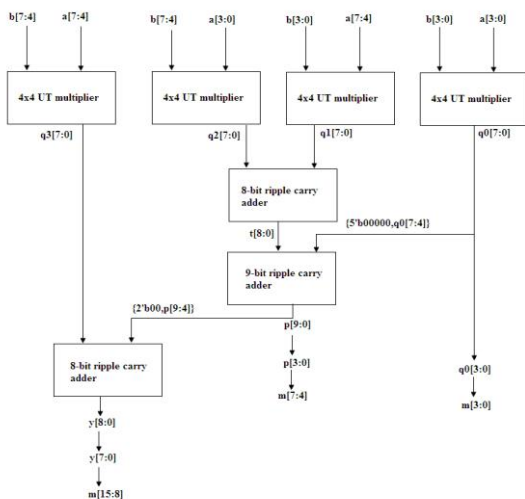
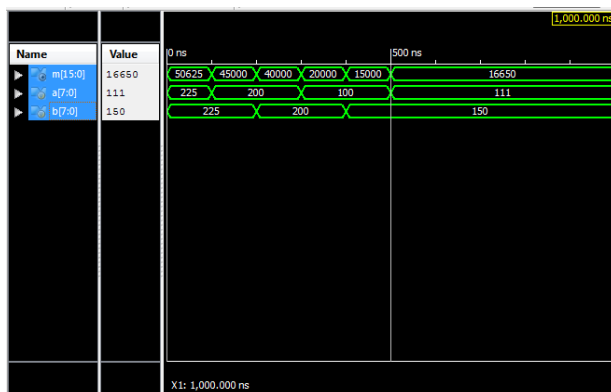


Figure: Reversible Logic Implementation of 8X8 UT Multiplier

RESULTS

Simulation Results:



Device Utilization Report:

Selected Device : 6slx16csg324-3

Slice Logic Utilization:

Number of Slice LUTs: 126 out of 9112 1%
 Number used as Logic: 126 out of 9112 1%

Slice Logic Distribution:

Number of LUT Flip Flop pairs used: 126
 Number with an unused Flip Flop: 126 out of 126 100%
 Number with an unused LUT: 0 out of 126 0%
 Number of fully used LUT-FF pairs: 0 out of 126 0%
 Number of unique control sets: 0

IO Utilization:

Number of IOs: 32
 Number of bonded IOBs: 32 out of 232 13%

Timing Report:

Timing Summary:

Speed Grade: -3

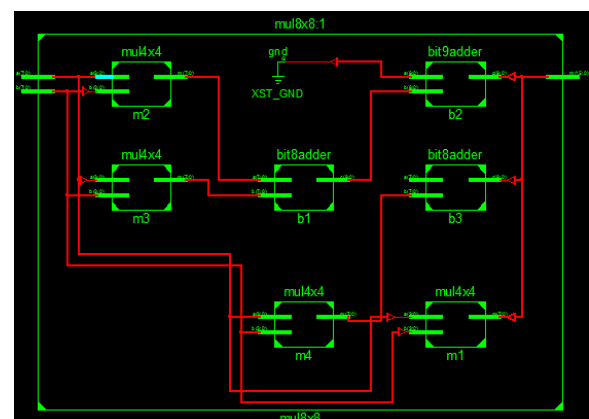
Minimum period: No path found

Minimum input arrival time before clock: No path found

Maximum output required time after clock: No path found

Maximum combinational path delay: 17.014ns

RTL Schematic:



CONCLUSION

In this thesis the Urdhva Tiryakbhayam Vedic Multipliers is realized using reversible logic gates. First 2X2 UT Reversible multiplier is designed using Peres gate and Feynmen gate. The ripple carry adders which were required for adding the partial products



were constructed using HNG gates. A 8-bit modified multiplier is designed. The 8-bit multiplier is realized using four 4-bit Vedic multipliers and modified ripple carry adders. Results also indicate a increase in the speed when compared to normal Vedic multiplier. This design has high speed, smaller area and less power consumption when compared with other reversible logic multipliers.

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