

Design of Arithmetic Logic Unit (ALU) using Modified QCA Adder

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Abstract:

Quantum cellular automata(QCA) is a new technology in nanometer scale to support nanotechnology. QCA is very effective in terms of high space density and power dissipation and will be playing a major role in the development of the Quantum computer with low power consumption and high speed. This paper describes the design and layout of a 2-bit ALU based on quantum-dot cellular automata (QCA) using Xilinx 14.4 synthesis and simulation tool. In ALU adder plays a vital role. In this survey a binary adder is taken for analysis and a new adder is designed based upon QCA technology. His modified novel bit adder is implemented into ALU structure. The aim of this proposed technique is that to reducing number of majority gates used in the design. This will lead to reduce number of QCA cells so that total area of ALU circuit can be minimized compare to previous designs. It also achieves reduced power consumption and high speed performances than all other existing ALU design which uses normal full adder.

Index Terms:

Moore's law, CMOS, Area, power consumption, Quantum dot Cellular Automata (QCA), Full adder, ALU.

I. INTRODUCTION:

A. CMOS Technology:

Microprocessor manufacturing processes was governed by Moore's law, and consequently microprocessor performance till now. Today many integrated circuits are manufactured at 0.25-0.33 micron processes. But recent studies indicate that as early as 2010, the physical limits of transistor sizing may be reached [2].

However the performance of various circuits in current CMOS-based architectures is close to reaching the limit. If the feature size of transistors is further reduced to a nanometer, it will produce quantum effects such as tunneling. Further, during device scaling process due to the effects of wire resistance and capacitance, the interconnections never scale automatically. Addition is an essential operation many Digital, Analog, or Control system [9]-[12]. Fast and accurate operation of all digital system depends on the performance of adders. The main function of adder is to speed up the addition of partial products generated during multiplication operation. Hence improving the speed by reduction in area is the main area of research in VLSI system design.

B. An Introduction to QCA Technology:

As an alternative to CMOS-VLSI, an approach called the quantum cellular automata (QCA) is developed in 1993[1] to computing with quantum dots. Unlike conventional computers in which information is transferred from one place to another by electrical current, QCA transfers information by means of propagating a polarization state from one cell to another cell [7]. The charge distribution in each cell is aligned along one of two perpendicular axes, so that the binary information can be encoded by using the state of the cell. Tree adder is an alternate to conventional adder, because by using tree structure carries are generated in parallel and fast computation is obtained at the expense of increased area so power usage is also increased. The main advantage of this design is that the carry tree reduces the number of logic levels (N) by generating the carries in parallel.

The parallel prefix tree adders are more favorable in terms of speed due to the complexity $O(\log 2N)$ delay through the carry path compared to that of other adders[6]. The rest of this brief is organized as follows: A brief introduction to the QCA technology is discussed in Section II, A brief introduction to the ALU is discussed in Section III and existing adders designed using QCA is given in Section IV, the novel adder design is then introduced in Section V, simulation and comparison results are presented in Section VI finally, in Section VII conclusions are drawn.

II BACKGROUND:

Quantum-dot cellular automata(QCA) is based on field coupled computing. States of a cell change due to mutual interactions of either electrostatic or magnetic fields. QCA Cell is the fundamental component of QCA Logic. Each QCA cell is made of four quantum dots in which two mobile electrons can be trapped which can tunnel between the dots. Due to the repulsion between the electrons, two electrons always take up the diagonal positions. Binary levels are represented by the positions of the electrons inside the cell unlike the voltage or current levels as in the CMOS. Fig.1 show the structures of quantum cell with two different polarizations (electrons are shown with black filled circular dots).

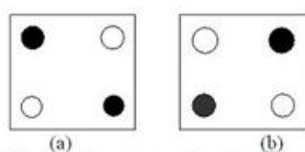


Fig.1. QCA cells with four quantum dots (a) cell with polarization $p = -1$ (Logic '0') (b) cell with polarization $p = 1$ (Logic '1')

Majority gate and Inverter are the two basic logic devices of QCA. Fig.2 shows the structure of the majority gate with 3 inputs, driver cell and output cell. Computation starts by driving the driver cell to the lowest energy state. Input cell changes its state by the signal which arrives towards the driver cell.

Driver cell always gets the binary value of majority of input signals since it is where the repulsion for the mobile electrons in driver cell is at minimum and output follows the state of driver cell.

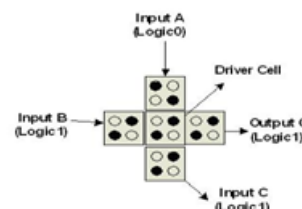


Fig.2 Majority Gate

The logic function for the majority gate is given by $M(a,b,c) = ab+bc+ca$ with a, b, c as boolean variables. In this way two input AND, OR gates can be designed by keeping the third variable as either 0 or 1 respectively. Inverter is the other basic logic device of QCA. If cells are placed diagonally to each other then they will have opposite polarizations. QCA Inverter is designed by this characteristic, such as shown in Fig. 3.

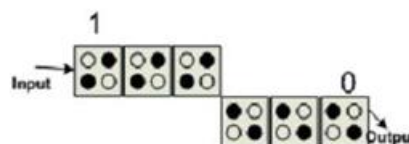


Fig.3. QCA Inverter

III.1- Bit ALU Architecture:

The Arithmetic Logic Unit (ALU) performs the basic arithmetic and logical operation. The ALU consists of arithmetic extender, logical extender and a full adder which is shown in Fig. 4. Three control signals will decide the operation of the ALU. M is the mode control variable which select between arithmetic and logical operations. $S1$ and $S0$ are selection line used in combination with M to select between the eight arithmetic and logical operation the ALU supports. Detail about Arithmetic and Logical extender is explained in [8].

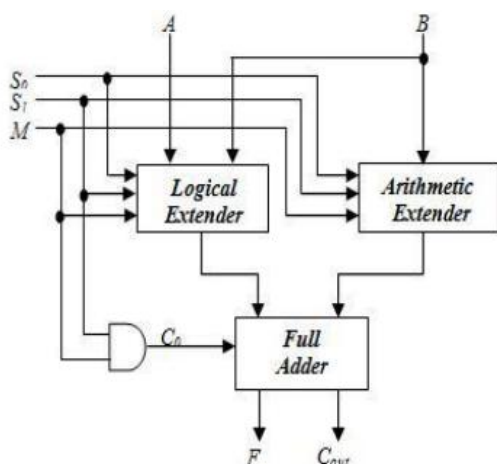


Fig .4: Architecture of ALU

Three control signals determine the operation of the ALU. M is the mode control variable used to select between arithmetic and logical operations. S1 and S0 are used in combination with M to select between the eight arithmetic and logical operation the ALU supports.

A. Arithmetic Extender

The Arithmetic extender modifies the second operand and passes it to the Full adder to the arithmetic as shown in Table I and Table II.

TABLE I. FUNCTION TABLE OF ARITHMETIC EXTENDER

M	S ₁	S ₀	Function name	Function	X	Y	C ₀
1	0	0	Decrement	A-1	A	all 1's	0
1	0	1	Add	A+1	A	B	0
1	1	0	Subtract	A+B'+1	A	B'	1
1	1	1	Increment	A+1	A	all 0's	1

TABLE II. TRUTH TABLE OF ARITHMETIC EXTENDER

M	S ₁	S ₀	B	Y
1	0	0	0	1
1	0	0	1	1
1	0	1	0	0
1	0	1	1	1
1	1	0	0	1
1	1	1	0	0
1	1	1	1	0
1	1	1	1	0

According to truth table we write Boolean equation of arithmetic extender shown in equation (1) and design logic circuit of arithmetic extender shown in fig. 5.

$$Y = M\bar{S}_1B + M\bar{S}_0\bar{B} \quad (1)$$

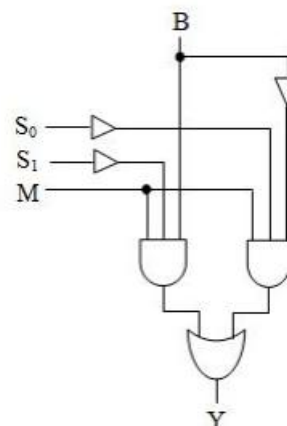


Fig 5: Logic Circuit of Arithmetic Extender

B. Logical Extender

The logic operations are performed in the logic extender as evident from Table III and Table IV. The FAs are used simply as connection for the outputs. According to truth table we write Boolean equation of logical extender shown in equation (2) and design logic circuit of logical extender shown in fig. 6.

TABLE III. FUNCTION TABLE OF LOGICAL EXTENDER

M	S ₁	S ₀	Function Name	Function	X	Y	C ₀
0	0	0	Complement	A'	A'	0	0
0	0	1	AND	A and B	A&B	0	0
0	1	0	Identity	A	A	0	0
0	1	1	OR	A or B	AB	0	0

TABLE IV. FUNCTION TABLE OF LOGICAL EXTENDER

M	S ₁	S ₀	X
0	0	0	A'
0	0	1	A & B
0	1	0	A
0	1	1	A B
1	X	X	A

$$X = \bar{M}\bar{S}_1\bar{S}_0\bar{A} + \bar{M}\bar{S}_1S_0B + S_0AB + S_1A + MA \quad (2)$$

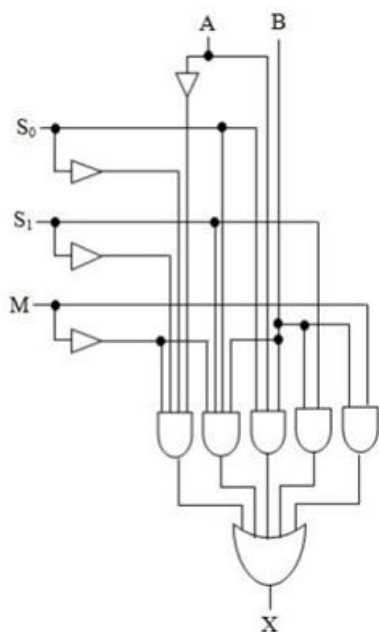


Fig 6: Logic Circuit of Logical Extender

IV.QCA Adders

A. Existing QCA Adders:

Several designs of adders in QCA are existing. The RCA [9], [11] and the CFA [10] process n-bit operands by cascading of n full-adders (FAs). A CLA architecture formed by 4-bit slices was presented [9]. n-bit CLA has a computational path composed of $7 + 4 \times (\log_4 n)$ cascaded MGs and one inverter. The parallel-prefix BKA [11] exploits more efficient basic CLA logic structures. Its main advantage over the previously described adders, the BKA can achieve lower computational delay. When n-bit operands are processed, its worst case computational path consists of $4 \times \log_2 n - 3$ cascaded MGs and one inverter. With the main objective tradeoff between area and delay, the hybrid adder (HYBA) described in [12] combines a parallel prefix adder with the RCA. For n-bit operands, this architecture has a worst computational path consisting of $2x \log_2 n + 2$ cascaded MGs and one inverter. When the methodology proposed in [13] was exploited, the worst case path of the CLA is reduced to $4 \times (\log_4 n) + 2 \times (\log_4 n) - 1$ MGs and one inverter. This approach can also be applied to design the BKA. In this case the overall area is reduced with respect to [11], but maintaining the same computational path.

By applying the decomposition method [14], the computational paths of the CLA and the CF A are reduced to $7 + 21 \log_2 (n/8)$ MGs and one inverter and to $(nil) + 3$ MGs and one inverter, respectively. Recently developed novel n bit adder [5] has separate structure for carry and sum generation. This adder has $5n-4$ number of MG's and n inverters for n bit adders. one problem in this structure is it will not produce correct output for LSB bit combination of input(aObO=Ol).for example for adding 2 numbers such as 2(10) and 3 (11) the actual output is 5(101)but this adder[5] will produce sum as 4(100).

B. Proposed QCA Adder:

In this section, we propose a two new QCA addition algorithm and the corresponding two-bit QCA adder structure that reduces the number of the majority gates and inverters required for existing designs [5] and eliminate above mentioned drawback also.

i.Modified Novel Bitadder 1:

To introduce proposed Modified novel bitadder 1 - n bit architecture first it is designed a 2bit basic module based on proposed algorithm. let us consider 2 operands such as $A = a_1a_0$ and $B = b_1b_0$ and we designed proposed 2bit module as shown in fig 7.1(a).For each bit the carry is generated by using one majority gate. Sum is calculated by cascading of 3 MG's. Given three inputs a, b, and c, the MG performs the logic function reported in (3). Provided that all input cells are associated to the same clock signal c1kx (with x ranging from 0 to 3).

$$M(a,b,c) = a.b + b.c + c.a \quad (3)$$

To create an n-bit adder, let consider two n bit addends $A = a_{n-1}, \dots, a_0$ and $B = b_{n-1}, \dots, b_0$ and for $i = n-1, \dots, 0$ and we arrange n proposed one-bit adders vertically in a column which is shown in fig7.1(b) and 7.1(c)respectively.

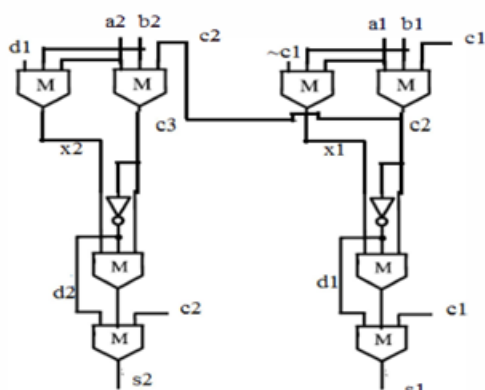


Fig 7.1(a): Modified novel bit adder 1: 2 bit basic module.

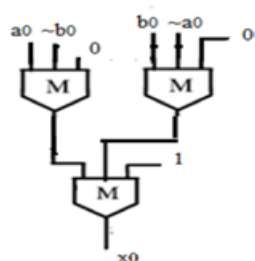


Fig 7.1(b): Modified novel bit adder 1-Calculation of x0

This proposed architecture can be implemented by using equation (4) and (5)

$$C_{i+1} = M(a_i, b_i, c_i) \quad (4)$$

$$S_i = M(M(a_i, b_i, d_{i-1}), M(a_i, b_i, c_i), d_i, c_i) \quad (5)$$

Where $d_i = \sim c_{i+1}$

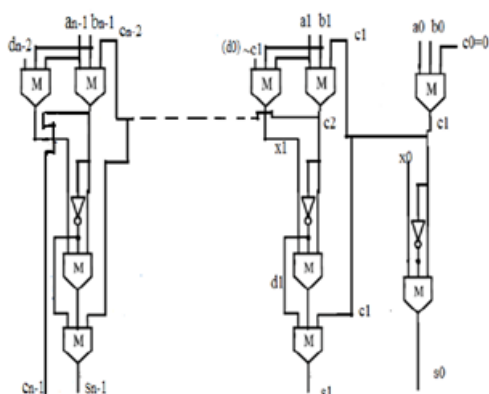


Fig 7.1(c): Modified novel bit adder I: n bit basic module

The proposed n bit QCA adder consists of $4n+1$ number of majority gates and $n+2$ inverters. It results in reduced hardware compared to the existing [5] structure and retains the simple clocking scheme.

ii.Modified Novel Bit Adder 2:

Here we now introduce a new Modified novel bit adder 2- n bit adder architecture which reduces hardware complexity compared to existing[5] and Modified novel bit adder 1 structure. The basic 2bit module for Modified novel bit adder 2 is shown in fig 7.2(a).Here the carry is calculated in same way as in proposed 1 structure and sum block is modified which requires two majority gates only.

This proposed architecture can be implemented by using equation (6) and (7)

$$C_{i+1} = M(a_i, b_i, c_i) \quad (6)$$

$$S_i = M(M(a_i, b_i, d_{i-1}), d_i, C_i) \quad (7)$$

Where $d_i = \sim c_{i+1}$

To create an n-bit adder, let consider two nbit addends $A = a_{n-1}, \dots, a_0$ and $B = b_{n-1}, \dots, b_0$ and for $i = n-1, \dots, 0$ and we arrange n proposed one-bit adders vertically in a column which is shown in fig 7.2(b).

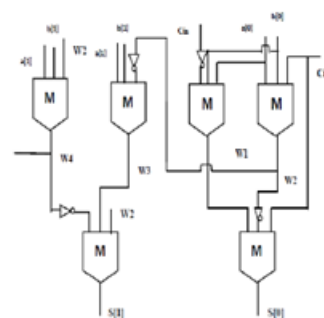


Fig 7.2(a): Modified novel bitadder 2: 2bit basic module

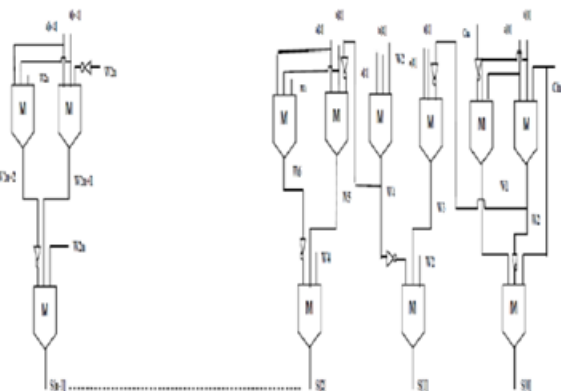


Fig 7.2(b): Modified novel bit adder 2: n bit adder

The proposed n bit QCA adder consists of 3n number of majority gates and n inverters. It results in reduced hardware compared to the existing [5] structure and pre-retains the simple clocking scheme.

V.SIMULATION RESULTS:

Simulation IS performed by using Xilinx 9.2i simulation tool and the operation is checked for all the input combinations. The synthesis and simulations are as shown below figures.

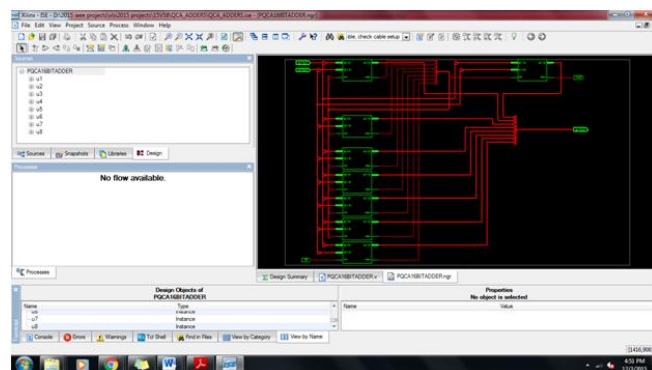


Figure.8.1(b): RTL schematic of Internal block of PQCA16BITADDER

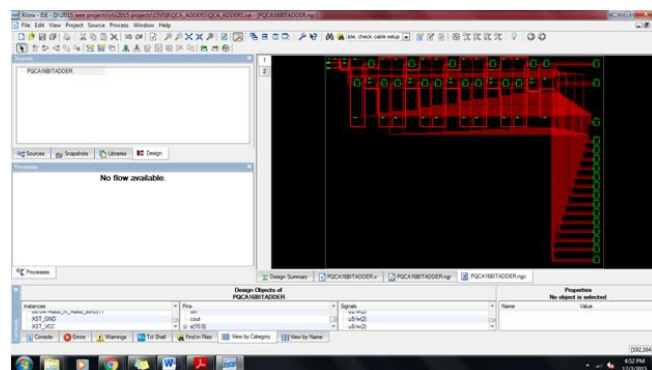


Figure 8.1(c) : Technology schematic of Internal block of PQCA16BITADDER

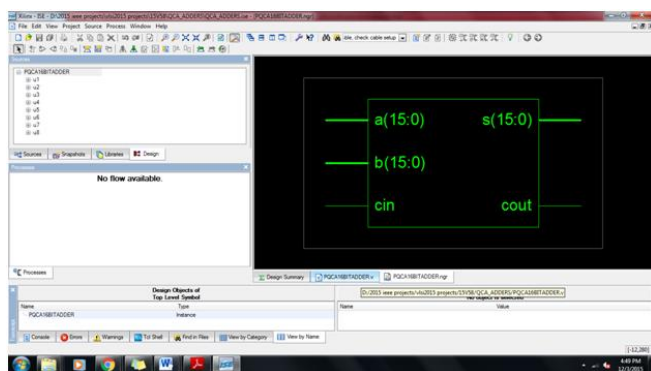


Figure 8.1(a): RTL schematic of Top-level of PQCA16BITADDER

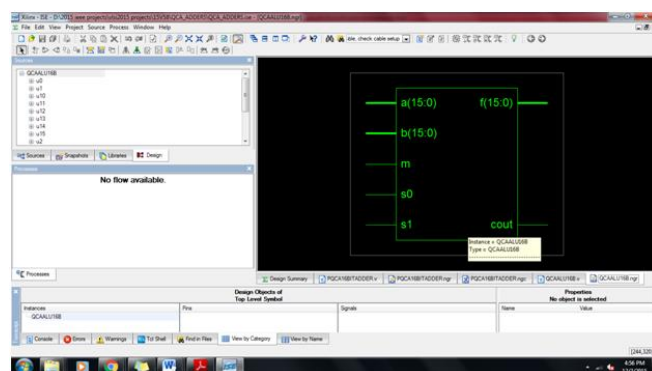


Figure 8.2(a): RTL schematic of Top-level of PQCA16BITALU

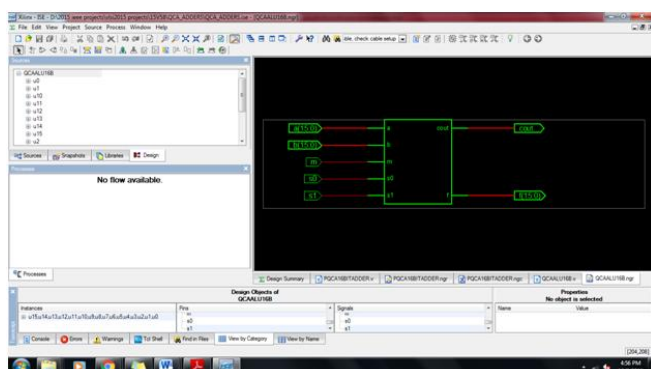


Figure.8.2(b): RTL schematic of Internal block of PQCA16BITALU

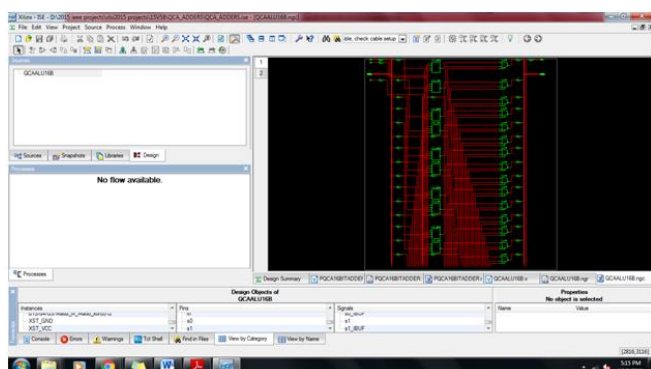


Figure.8.2(c) : Technology schematic of Internal block of PQCA16BITALU

Table V: Synthesis report of PQCA16BITADDER

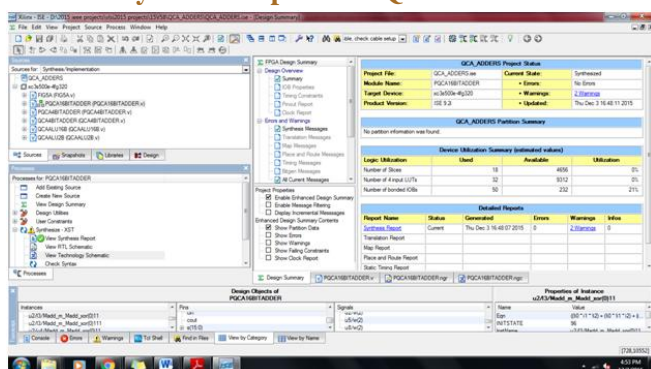


Table VI: Synthesis report of PQCA16BITALU

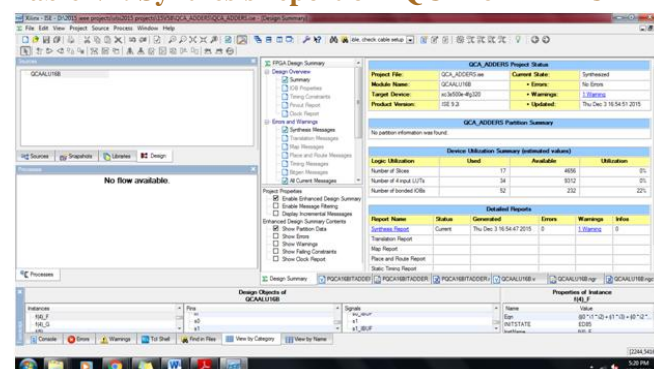
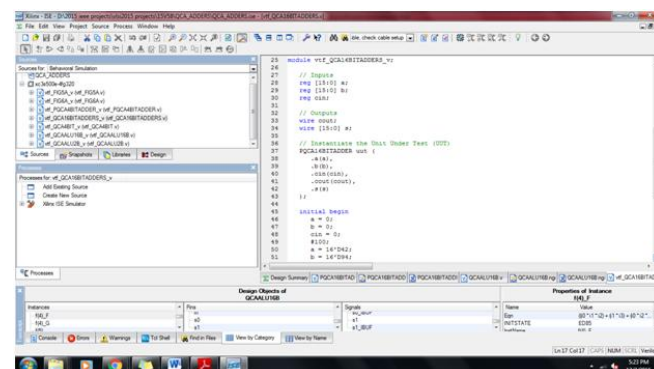



Figure 9.1(a): Test Bench for PQCA 16BIT ADDER

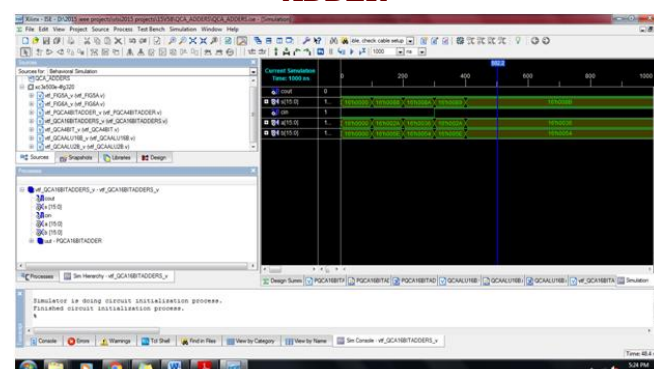


Figure.9.1(b): Simulated output for PQCA 16BIT ADDER



A simple approach is proposed in this paper to reduce the area and power of adder architecture. The logic operations eliminated all the redundant logic operations of the conventional adder and proposed a new logic formulation for the adder. A new adder in QCA technology was designed which achieves reduced area than all the existing QCA adders [5]. The Proposed modified novel bit adder 2 is implemented in 1 bit ALU circuit to improve the efficiency. The proposed ALU has total gate count of 54 which is reduced than existing ALU [8] in which gate count is 66. The delay required for proposed ALU structure is 11.904ns which is less than existing in which 15.433ns is needed. The functionality is checked by using Xilinx ISE 9.2i simulation tool The Future extension of our work is to design 16 bit ALU in QCA using Modified novel bit adder 2 structure.

The proposed work can be extended to design of area efficient and high speed Multiplier and Accumulators (MAC) and digital code converters

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