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DESIGN OF REVERSIBLE LOGIC BASED RAM USING QCA

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ABSTRACT
Nanoscale quantum dots are the building blocks of the computing approach known as quantum dot cellular automata (QCA). Through interactions between quantum dots and the use of tunneling phenomena and charge polarization, it manipulates binary data. QCA provides atomic-level scalability, high-speed operation, and low power consumption. Challenges include fabrication complexity, temperature sensitivity, and integration with existing technology. Exor 1 is the most energy-efficient, with a decrease in energy dissipation of 96.10% compared to Exor 4. Exor 2 follows with a decline of 71.29%, and Exor 3 shows a smaller decrease of 15.6%. Exor 4 has the highest energy dissipation among them. Mux2 exhibits an overall reduction in energy dissipation of 80.32% when compared to Mux1, with significant fluctuations in percentages, including an unexpected increase of 211.47% in one case. With fewer cells and a different energy efficiency than Mux1 and Mux2, Mux3 is unique. Compared to the Feynman gate, the Peres gate exhibits an enormous 354.08% reduction in energy dissipation, making it stand out for its exceptional energy efficiency. Furthermore, the Toffoli gate exhibits a noticeable decrease of 211.22%, whereas the Fredkin gate has a decrease of 232.90% in relation to the Feynman gate. This shows the greater energy efficiency and distinct cell count of the Peres gate over the other logic gates. This design was implemented by using QCA designer tools 2.0.3.

Keywords: —
Quantum Dot Cellular Automata (QCA), EXOR gates, Multiplexer, Reversible gates.

INTRODUCTION
In terms of potential speed, device density, and power efficiency, CMOS technology is inadequate [1]. CMOS is a complicated fabrication process, more radiation-prone, and might perform less well in analog applications. Its vulnerability to noise, which can impair the dependability and general efficiency of electronic devices is one of its main drawbacks. Furthermore, CMOS circuits may have trouble operating in high-temperature conditions and have a higher power consumption than some other technologies. In comparison to Complementary Metal-Oxide-Semiconductor (CMOS) technology, Quantum-dot Cellular Automata (QCA) exhibits several advantages, including ultra-low power consumption, high-speed operation, reduced size for more compact circuitry, and enhanced resilience against certain radiation-induced faults [1]. The core components of QCA circuits are majority and inverter gates, which have a direct effect on the system's overall efficiency [2]. Furthermore, QCA technology circuits can be created in two categories: reversible and normal [2]. QCA has been widely employed by researchers to examine reversible logic; hence, enhancing the functionality of reversible gates and circuits can raise system efficiency as a whole [2].

LITERATURE SURVEY
This study designs a D-latch, a unique 2-1 mux with less cells and lower energy dissipation, as well as a novel QCA RAM that enables synchronous set and reset. However, as the RAM architecture follows a four-phase clocking scheme, as memory capacity increases, it becomes more challenging to dissipate accurate clock signals uniformly over the whole circuit.[18]. A new reversible 3x3 gate circuit design in QCA consists of 21 cells in a single layer and a 0.046 μm2 area with a 0.25 clock cycle delay but the circuit has huge consumption area and high cell count.[19]. The design of Quantum-dot Cellular Automata (QCA) to create a RAM cell in a crossbar architecture. Large memory designs are possible with this implementation, although it takes up more space than other methods.[20]

ABOUT QCA

A. Quantum Dot cellular Automata(QCA) The emerging field of Quantum Dot Cellular Automata has broad usage in many studies that are focused on optimizing circuits at the nanoscale.[3]. A QCA cell is a square with two free electrons and four quantum dots, one in each of the four corners [1]. There are two polarization values "1" and "−1" because of the electron mutual repulsion. In a QCA cell, binary value "1" is presented if polarization is 1, and binary value "0" is presented if polarization is −1. QCA's core components are wire and three-input majority inverter and gate (M3). By establishing the polarization, the M3 will apply logic "AND" by setting the polarization of any one input cell to "-1," and by doing so, it will apply the "OR" logic.

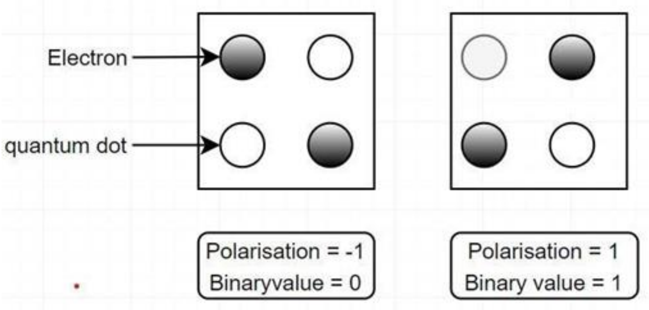

Fig1: Quantum cells in QCA [3]

CLOCKS IN QCA

When compared to CMOS circuits, the primary advantages associated with QCA technology are its reduced power, quicker response time, and reduced area utilization. There is no voltage source in the QCA circuit.[5]. Due to its extremely low read and write energy consumption, QCA- based memory cells have become increasingly significant in recent years.[5] The QCA cells' electrons align themselves to create logic 0 and logic 1. The QCA cells electron orientations will determine how logic values are transferred within the circuits.[5]. In QCA circuits, the clock regulates the flow of electrons within the cells.

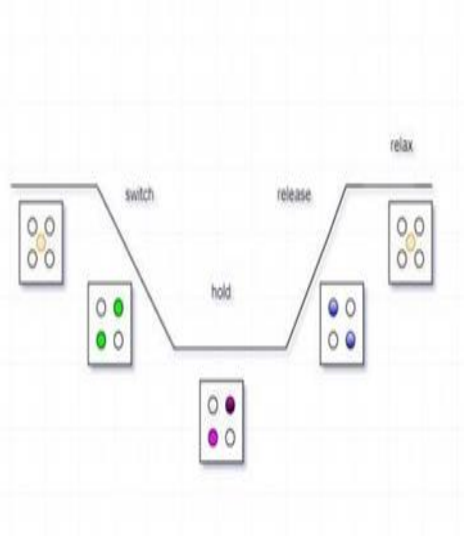

Fig2: Clocking mechanism [4]

EXISTING METHOD

IMPLEMENTATION OF DIFFERENT QCA DESIGNS

***A.* Design of exor gate using quantum dot cellular automata**

The ultra-efficiency of the XOR operation's design suggests that performance and improving resource efficiency are the primary goals. The ALU design findings indicate the XOR operation's superiority over earlier designs in terms of area, complexity, and delay, focusing on its critical role in attaining overall better performance.

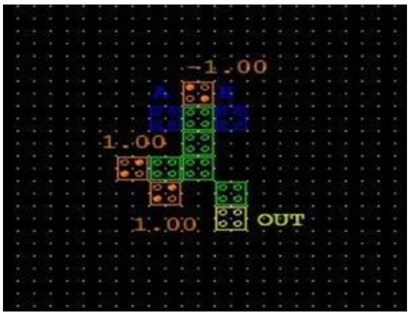

Fig3:Exor1 [5]

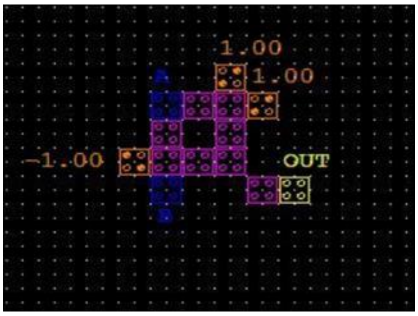

Fig4:Exor2 [6]

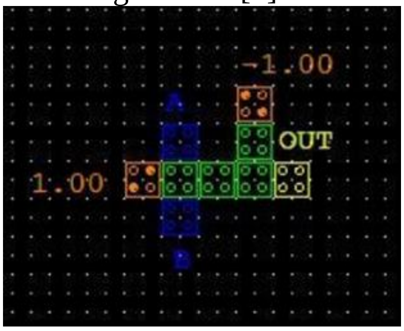

Fig5:Exor3 [7]

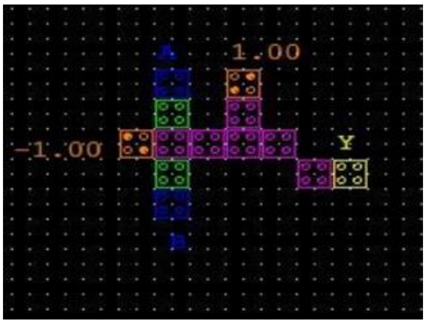

Fig6:Exor4 [8]

B. Design of multiplexer using quantum dot cellular automata

A multiplexer is a device that sends several data at once and is widely used in communication systems. Thus, this work presents a practical structure based on the innovative XOR gate for implementing a 2 to 1 multiplexer. This structure may also be utilized as a module to create 4 to 1 and 8 to 1 multiplexers. The effectiveness of the recommended designs is evaluated using simulations conducted with the QCA Designer program.

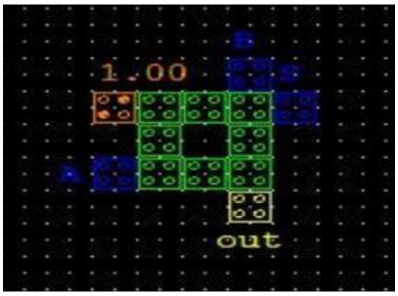

Fig7:Mux1 [9]

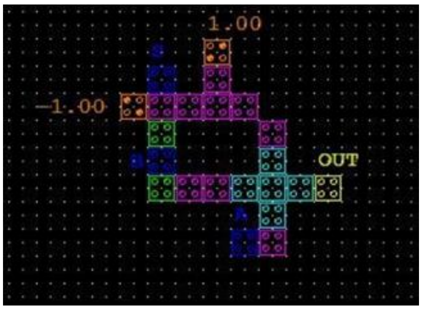

Fig8:Mux2 [10]

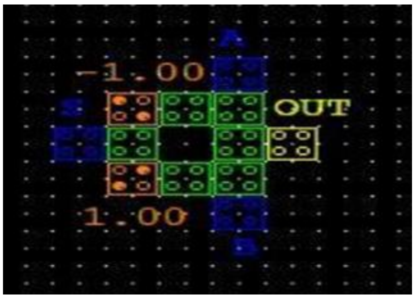

Fig9:Mux3 [11]

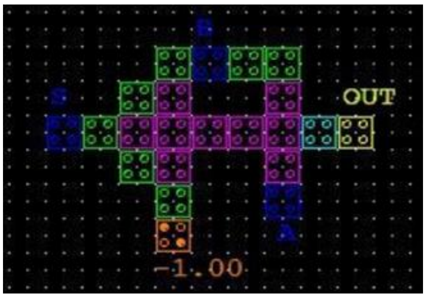

Fig10:Mux4 [12]

C. Design of reversible gates using quantum dot cellular automata

Quantum-dot Cellular Automata (QCA) designs of reversible logic gates are utilized to achieve significant reductions in cell count and area compared to prior designs. Acquiring better delay for Feynman gates while keeping Fredkin and Toffoli gates at constant delay intervals. Feynman gate is evolved implement quantum simulation operations which is useful for quantum algorithm development and quantum system modelling in QCA. Fredkin gate is also known as controlled swap gate as it is mostly used for swapping two input bits based on a control bit. Toffoli gate is advantageous of error correction and fault tolerant quantum computing. Both Toffoli gate and Peres gate can be used as universal reversible gate. Therefore, all of the fundamental Boolean functions are implemented using these gates.

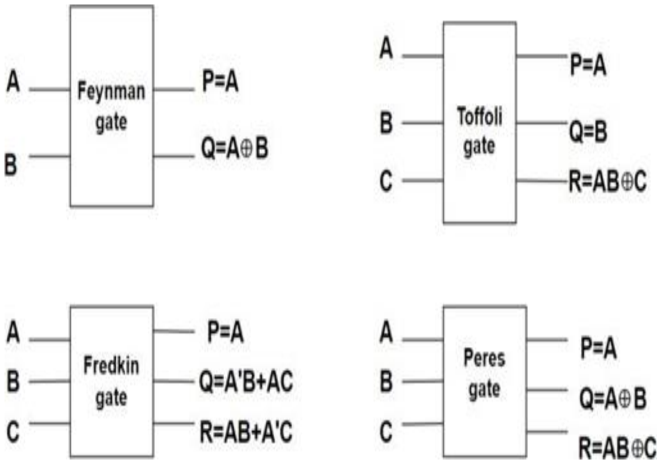

Fig11: Block diagram of different reversible gates [13]

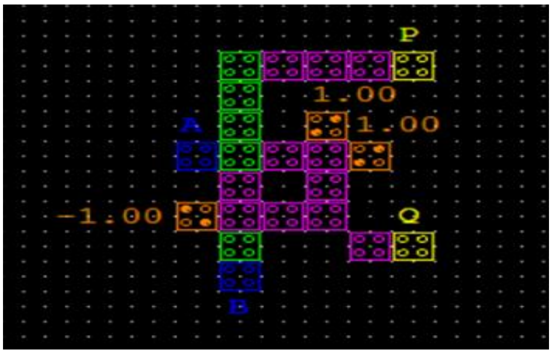

Fig12:Feynman gate [14]

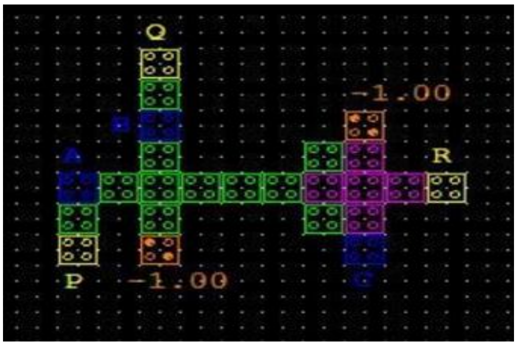

Fig13:Toffoli gate [15]

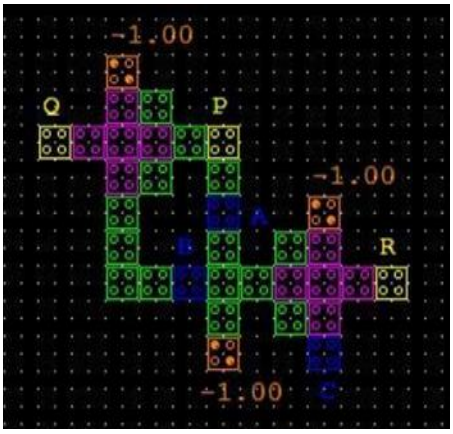

Fig14 :Peres gate [16]

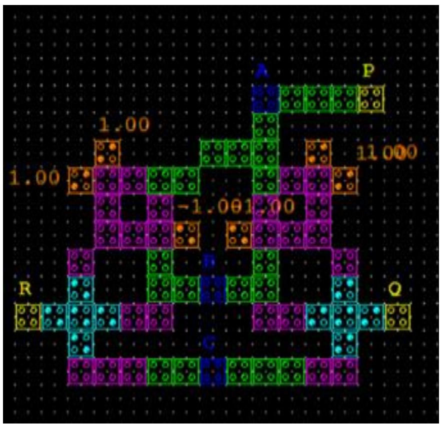

Fig15:Fredkin gate [17]

D. Design of RAM using quantum dot cellular automata

Input can be stored in the latch by IN starting the "Write" process if WR/RD'=1; Select = 1. The "Read" function is enabled when the previous output of the D latch is recorded back into the latch if WR/RD' = 0. When WR/RD' =1, E=1 Since OUT = IN (the same as input) when = 1, the write operation is carried out and if E = 0 Writing is not allowed because 0, OUT is the same as the preceding output. If E = 1, WR/RD' = 0, then the output is the same as it was before. Consequently, read operation is executed. As a result, the suggested RAM cell can execute all needed read and write functions more effectively with enhanced results in terms of area, number of cells, and latency.

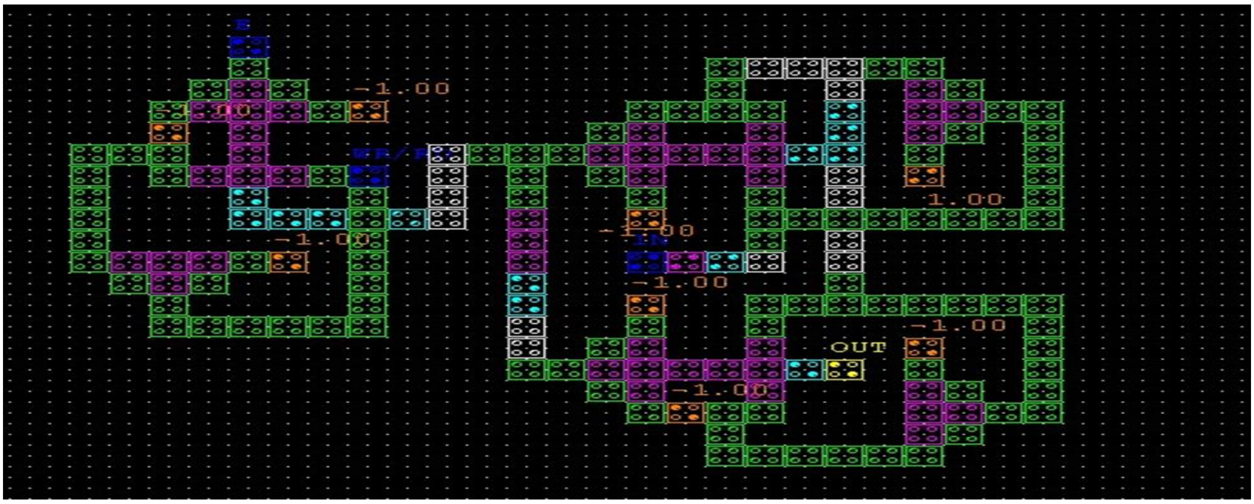

Fig16: REVERSIBLE RAM[12]

RESULTS AND DISCUSSION

The gate has an improvement of 41.1% in gate count, 44.4% in total area, 41.3% in cell area, and 75.43% in cost function as com- pared to Chabi et al., 25 which is the most cost- efficient gate in the existing literature.

A. EXOR GATES

Upon analyzing the energy dissipation between several Exor's, notable differences become apparent. Compared to Exor 4, Exor 1 exhibits a significant decrease in total energy dissipation of 96.10%. Likewise, Exor 2 displays a notable decline of 71.29%, although Exor 3 displays a somewhat smaller decline of 15.6%. Moreover, Exor 3's average energy dissipation shows different percentage decreases from 16.66% to 71.68% in comparison to Exor 4. These results imply that Exor 4 is not only different in terms of the number of cells but also has a different function in energy dissipation in relation to the other Exor's.

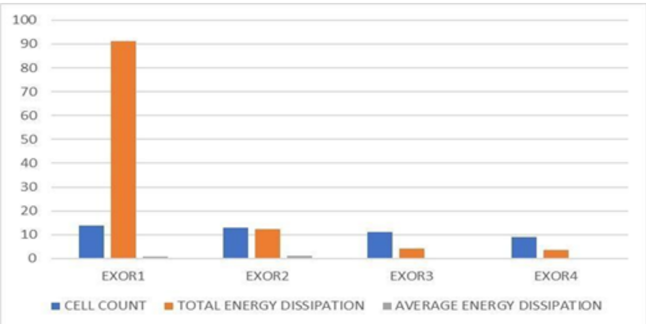

Fig 17 – Comparison of cell count, Total energy dissipation(eV), Average energy dissipation(eV) of different EXOR gates

B. Multiplexer

When it comes to multiplexers, Various multiplexers' energy dissipation characteristics can be analyzed to find the patterns. More specifically, compared to Mux1, Mux2 exhibits a significant 80.32% decrease in overall energy dissipation. Additionally, differences in the overall energy dissipation percentages are noted, exhibiting decreases of 17.73% and an unanticipated rise of 211.47%. These differences also apply to Mux2's average energy dissipation, which shows a startling 211.47% fall in comparison to Mux1 along with steady declines of 80.32% and 17.70%. These results highlight the complex energy dissipation dynamics in the multiplexer domain, where Mux3 is notable for both its reduced cell count and its distinct function in energy efficiency compared to Mux1 and Mux2.

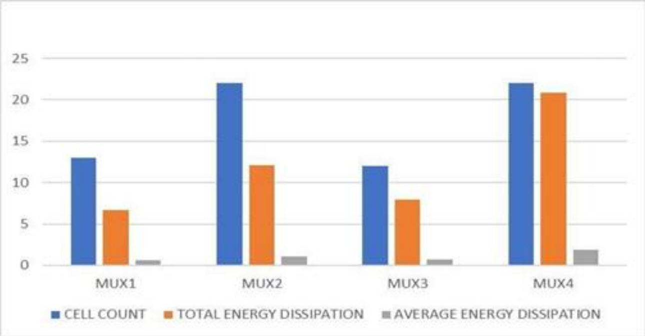

Fig18: Comparison of cell count, Total energy dissipation(eV), Average energy dissipation(eV) of different Multiplexers

C. Reversible gates

The Peres gate is unique among logic gates in that it has fewer cells than its equivalents. Examining the energy dissipation properties of various gates yields fascinating information. The Toffoli gate shows a significant reduction in total energy dissipation of 211.22% when compared to the Feynman gate. The Peres gate's energy efficiency is even more impressive, exhibiting an astounding 354.08% drop. The overall energy dissipation of the Fredkin gate also shows a significant decrease, falling by 232.90% when compared to the Feynman gate. This pattern also applies to average energy dissipation: in comparison to the Feynman gate, the Toffoli, Peres, and Fredkin gates exhibit notable reductions of 211.36%, 354.41%, and 232.39%, respectively. These results highlight the unique cell count of the Peres gate as well as its superior energy efficiency in comparison to other logic gates like the Feynman, Toffoli, and Fredkin gates.

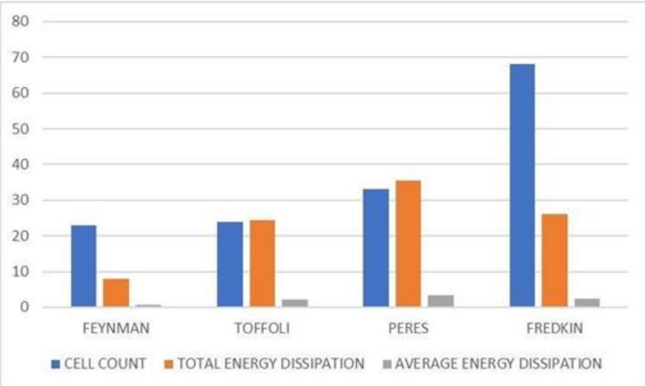

Fig19: – Comparison of cell count, Total energy dissipation(eV), Average energy dissipation(eV) of different Reversible gates

D. Area

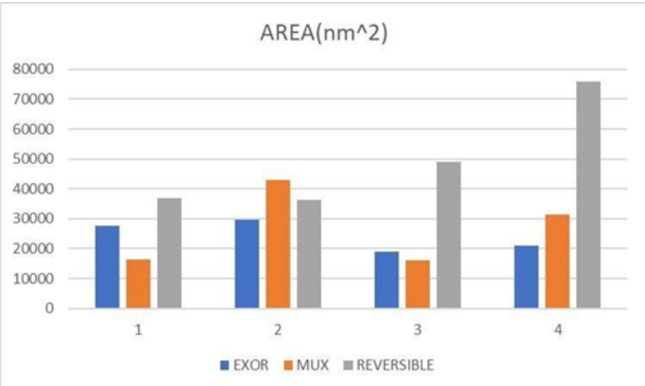

Fig20 – Comparing the areas of EXOR, Multiplexer and Reversible gates

CONCLUSION

In conclusion, QCA has enormous potential for advancing computing technology in the future because of its better functionality, efficiency, and performance compared to CMOS. Out of all the Exor gates, Exor 1 is the most energy- efficient. Mux 2: Although erratic, exhibits a notable energy saving over Mux1.Compared to other logic gates like the Feynman gate, the Peres gate has remarkable energy efficiency with a significant decrease in energy dissipation.

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