Webology (ISSN: 1735-188X)
Volume 18, Number 6, 2021

Systematic Review On Efficient Nano Circuit Structures Using Qca Technology

Swagata Das[1] , Dr. Rahul Mishra[2]

[1,2]Department of Electronics & Communication Engineering, Dr. A.P.J. Abdul Kalam University, Indore, M.P., India.

ABSTRACT:
The current is flowing towards scaling Complementary Metal Oxide Semiconductor (CMOS) VLSI circuits in response to the growing demand for low power and attractively fast devices. However, continued scaling of CMOS circuits is limited by quantum mechanical phenomena caused by scaling at the sub-micron and nano-level. Scientists are investigating novel characteristics of the nano regime that may provide an answer to this predicament. In this article, systematic review on efficient nano circuit structures using QCA technology has been discussed.

Keywords: Nano, Circuit, Structures, QCA, Technology.

INTRODUCTION:

The International Technological Roadmap for Semiconductors (ITRS) paper from 2005 provides a summary of potential technological solutions, including nanotechnology, to these issues. The quantum-dot cellular automata (QCA) introduced by Lent et al. (1993) is a nanostructure paradigm that uses arrays of connected quantum dots to accomplish Boolean logic functions. QCA's tiny spots, considered to be a useful, and minimum power device enable extensive compact.

SYSTEMATIC REVIEW OF LITERATURE:

Jadav Chandra Das and Debashis De (2020) researched that quantum-dot cellular automata (QCA) have been proposed as a potential substitute for complementary metal-oxide-semiconductor-based technology. Reversible computing should, ideally, help achieve zero power dissipation. This paper proposes a revolutionary QCA-based reversible priority encoder design. Toffoli and BJN gates serve as the design's fundamental building elements. The QCA designer simulator validates the suggested design. The simulation findings examine the performance of the reversible priority encoder. By using reversible logic, the suggested encoder reduces the amount of heat energy dissipation while simultaneously solving the issue of the messy code. Since reversible logic allows for zero information loss, the suggested reversible circuit may play a significant role in future wireless communication. Researchers investigated the power requirements of the suggested QCA circuits, indicating that QCA would be an ideal platform for implementing reversible circuits. Also mentioned is the connection to recently proposed work. [1]

Hani Alamdar et al. (2020) explored that electronic devices now confront basic hurdles in parameters like speed, frequency, and power consumption for CMOS technology circuits because it is not possible to further reduce the dimensions. Substituting quantum-dot cellular automata (QCA) technology for CMOS technology is one way to solve the problem. Researchers have conducted extensive studies on digital circuit design in QCA technology. In electrical and communication systems, one of the key components is the phase-frequency detector (PFD). This study presents a PFD structure in QCA technology for the first time. A D-fip-fop (D-FF) with reset capability based on a new inverter gate is employed in the suggested structure. In contrast to earlier inverters, the new inverter gate of this D-FF produces an output signal with a high degree of polarization. The suggested PFD is smaller than the PFD constructed with a typical inverter, with 199 cells, occupying an area of 0.22 μm2, and having a latency of two clock cycles. [2]

Syed Umira R. Qadri et al. (2019) investigated that quantum dot cellular automata are a novel technology that aids researchers in creating various digital circuits. However, digital architectures lack widespread acceptance. Consequently, the design of these digital circuits has become necessary to guarantee authenticity through various security components, like a multiplexer, which aids in secure message transfer as a cryptographic component to reserve a clock cycle or modify the channel separation track, among many other practical circuit designs. In quantum dot cellular automata, this study provides new and efficient structures of 2:1, 4:1, and 8:1 multiplexers without any cross-over, which is useful for data transfer. We compared the three presented multiplexers with some of the most recent structures in terms of cell count, cell area, speed, latency, complexity, and other factors. The comparisons show significant improvements. Additionally, the given multiplexer architectures are fully functional and resilient at high temperatures and frequencies, and they can be employed as a cryptographic element in secure message exchange, according to simulations conducted with the QCA Designer and QCA Pro software programmes. [3]

Harshitha S. et al. (2019) found that quantum-dot cellular automata (QCA) are an emerging technology used for nanoscale computation. It's a great substitute for traditional CMOS technology. For logical circuits, QCA offers us low energy consumption, high speed, quicker switching speed, and compact shapes. A scan flip-flop is used for device testing. Testing is an essential component of design verification. Processors use it for an integrated self-test. In contrast to earlier architectures, the goal of this research is to build an optimised scan flip-flop topology that requires less space and energy consumption. The number of cells, energy dissipation, and area occupied by the logical circuit are used to analyse the efficiency of the suggested structure. With a cell count of 32 and an energy dissipation of 0.0105 eV, the proposed scan flip flop is 20% and 29% more efficient than the earlier versions. For design and simulation, QCADesigner is a CAD tool. The cells have a separation distance of 2 nm and dimensions of 18 nm in height and 18 nm in width. The simulation tool makes use of bi-stable and coherence vector simulation engines. [4]

Md. Abdullah-Al-Shafi and Rahman Ziaur (2019) stated that one of the most prominent archetypes of field-coupled nanoscale devices is the quantum-dot cellular automaton (QCA). It is a minimally dissipated, non-von Neumann model for transistor-free logic in conventional nanocomputing. Restricted field connections between nanoscale constructions modules arranged in shapes are relied upon by field-coupled nanoscale models for practical evaluations. A few flexible charges create a lattice of connected dots to form a basic QCA device known as a cell. The charge arrangement starts a bit, and quantum charge channeling inside a squared cell allows device shifting. Higher switching speeds, room-temperature implementation, and extreme device thicknesses are approved by QCA operation. In this paper, we provide an innovative design of two widely used sequential circuits: the serial-in/serial-out (SISO) register and random-access memory (RAM). Both systems have achieved notable improvements in scope, cell complexity, latency, and expense. Extensive performance evaluation and analysis validates the exceptional performance of the developed circuits relative to previous research in multiple domains. The exact functionality of the described architectures has been verified using the QCADesigner and QCAPro programmes. [5]

Ismail Gassoumi et al. (2019) stated that one of the most crucial design goals in contemporary digital image processing systems is power optimization. Since DCT is regarded as one of the most important methods in image and video compression systems, researchers have done a number of in-depth studies on power optimization. However, quantum-dot cellular automata (QCA) may offer a fresh approach to creating highly parallel structures and algorithms that boost the efficiency of systems that interpret images and videos. In addition, it has a number of benefits over CMOS technology, including its small size, high operating frequency, and incredibly low power dissipation. Thus, using QCA technology, the authors of this study suggest a multiplier-less DCT architecture. In comparison to the current conventional architectures, the proposed design offers superior circuit performance, extremely low power consumption, and very compact dimensions. For QCA circuit design and functional verification of all designs in this work, the QCADesigner tool has been used. The suggested circuit's power dissipation is estimated using QCAPro, a widely used power estimator tool. In terms of power, the recommended design outperforms the traditional option by 53%. It is obvious that the results of this work will present low-power image processing systems with new opportunities. [6]

Shiv Bhushan Tripathi (2018) explored that the research, morphological processes, including dilatation and erosion, are crucial for a variety of video and image processing applications. In this work, a reconfigurable quantum-dot cellular automata (QCA) nanocircuit for morphological image processing applications is presented. QCA is a developing nanotechnology that is field-coupled and can be used in a variety of image processing tasks. Two cascaded 5-input majority voters are used in the implemented QCA design, and a control line is used to facilitate dilation and erosion. Comparing the suggested design to the earlier findings reveals a significant improvement in terms of area, delay, and cell count. [7]

Radhouane Laajimi (2018) investigated that an innovative digital technologies invariably result in high density and extremely low power usage. One of these ideas is based on Coulomb repulsion and is known as quantum-dot cellular automata (QCA), one of the new emerging nanotechnologies. A new design of 2-input Exclusive-NOR (XNOR)/Exclusive-OR (XOR) gates is presented in this chapter. The 3-input Exclusive-NOR (XNOR) gates are made up of 10 cells in 0.006 μm2 of space. A 3-input Exclusive-OR (XOR) gate with a unique layout is characterized by 12 cells on 0.008 μm2 of space. Compared to the best published design, the suggested 2-input XOR/XNOR gate topologies offer lower area and complexity. Version 2.0.3 of the QCA Designer tool was used to achieve the simulation results of the suggested designs [8].

Quantum-dot cellular automata (QCA) are one of the few potential new technologies for computing at the nanoscale, according to A. Rezaei (2018). This study presents novel designs for several QCA sequential circuits. A 5-bit counter, a novel single edge generator (SEG), and a divide-by-2 counter are constructed using an efficient QCA D flip-flop (DFF) architecture. A new edge-triggered K-pulse generator (KPG) and a negative pulse generator (NPG) are also introduced for use in QCA, along with a few oscillator types. With no wire crossing, the sturdy layouts of the suggested circuits are created, put into practice, and simulated using the QCADesigner program. Analysis is done on the fault effects at the proposed DFF's output caused by the missing cell flaws. Furthermore, the suggested QCA designs' resilience to temperature changes is assessed. The suggested designs are contrasted with traditional CMOS technology and earlier QCA developments. The results of the simulations verify that the new QCA architectures function as intended and are easily applied to the construction of QCA sequential circuits. [9]

B.S. Premananda et al. (2018) found that quantum-dot cellular automata (QCA) is a relatively new nanotechnology that has a lot of potential to produce compact circuits using less energy than CMOS technology. Compact and low-power adder and multiplier designs are required due to the growing need for effective signal processing. Although they require more time than n-bit parallel adders, serial adders are area-efficient architectures that can compute n-bit addition with a single adder. Compared to multipliers that use more intricate multiplication methods, serial-parallel multipliers have regular and scalable architectures. This work proposes a 4-bit QCA-based serial-parallel multiplier circuit that is energy- and area-efficient. Prior to the realization of a 2-bit serial-parallel multiplier, a QCA-based serial adder is constructed. A 4-bit serial-parallel multiplier is created by scaling up this multiplier. QCADesigner-E is used to design, analyze, and simulate the QCA circuits. The number of cells, total area, and energy dissipation are used to evaluate designed circuits. The simulation findings suggest that, in comparison to reference architectures, the suggested 4-bit serial-parallel multiplier minimizes the number of cells, area, and energy dissipation. [10]

Zahid Shakee et al. (2017) stated that quantum dot cellular automata (QCA) is a developing technology that could provide an alternative to the VLSI industry's trend towards scaling down. Its advantages include improved switching speed, reduced power consumption, and its small size. Many advanced frameworks frequently use QCA as a component, positioning it as a strong competitor for future digital systems. As a result, researchers have implemented many logic functions based on QCA thus far. This study provides an effective XOR gate. The model demonstrates the design ability of combinational logic circuits. Research has proven that the suggested XOR gate can create logic circuits for QCA. In digital systems, the most basic component is the adder circuit. The suggested XOR gate is used to develop effective half-adder and half-subtractor circuits. We contrast the performance evolutions of the suggested XOR circuits with those of their traditional counterparts. Using the QCA Designer simulation programme version 2.0.3, the suggested designs' functionality and circuit operation have been verified. [11]

Abilash. B et al. (2015) found that the two main problems with circuit design are area and complexity. The number of transistors that can fit in a single die increases as they get smaller, improving the processing capacity of the chip. Transistors, however, are limited by their current size. One potential way around this physical limit is the quantum-dot cellular automata (QCA) technique. A fundamental part of QCA arithmetic circuits is the suggestion of using a Ripple Carry Adder (RCA) module. The adoption of so-called minority gates in addition to the more conventional majority voters was the primary methodological design advance over current state-of-the-art alternatives. QCA Designer 2.0.2 is used to create and simulate the suggested adder. According to simulation results, the suggested adder decreases area delay more effectively than earlier designs and surpasses all state-of-the-art competitors. [12]

Quantum-dot cellular automata (QCA) are a type of transistorless computing that uses the arrangement of charges between quantum dots to store binary data, as shown by Chabi, Amir Mokhtar, et al. (2014). The basic QCA logic primitives used to create a variety of QCA circuits are majority and inverter gates. Our work presents a novel method for creating effective QCA-based circuits by rearranging majority gates with three and five inputs to obtain Boolean expressions. While the exclusive-or and multiplexer are the most crucial basic logical circuits in digital systems, QCA technology offers the benefit of efficient single-layer structure design without the need for coplanar cross-over wiring. We develop simple and dense multiplexer and exclusive-or structures to demonstrate the effectiveness and utility of the suggested technique. Compared to earlier ideas, the suggested designs significantly improve in terms of space, complexity, latency, and gate count. The QCA designer tool has verified the correct logical functionalities of the provided structures. [13]

T. Mohammad Rafiq Beigh et al. (2013) explored that the quantum-dot cellular automaton (QCA) is a possible nano-electronic computational architecture of the future that stores binary information as the electronic charge configuration of a cell. It is a digital logic architecture that performs binary operations with single electrons arranged in arrays of quantum dots. QCA circuits are constructed using QCA cells, which serve as the basic building blocks. QCA architectures utilize QCA cells, which serve as fundamental building blocks for constructing basic gates and logic devices. This work assesses the performance of multiple QCA-based XOR gate implementations and suggests multiple innovative layouts with improved performance parameters. We discussed several QCA circuit design approaches for XOR gates. The traditional layouts currently documented in the literature have more crossovers and cells compared to these layouts. These design topologies serve particular purposes in circuit applications that rely on communication. They are very helpful in arithmetic processes, error detection and correction circuits, and phase detectors in digital circuits. There is also a comparison of several circuit designs provided. More intricate circuits can be realised with efficiency by utilising the suggested designs. We conducted the simulations in the current study using the QCA Designer tool. [14]

Quantum-dot cellular automata (QCA) are one of the few alternative computing platforms that Mohsen Hayati and Abbas Rezaei (2012) found have the potential to be a promising technology because they are smaller, faster, and consume less power than CMOS technology. An optimised full comparator is suggested in this letter for use in QCA. We compare the area, delay, and complexity of the suggested design to earlier efforts. Our design exhibits an improvement in cell count and area of 64% and 85%, respectively, above the best preceding whole comparator. Furthermore, we implemented it using a single clock cycle. The acquired data demonstrate that, in comparison to the earlier designs, our full comparator is more efficient in terms of cell count, complexity, area, and delay. Therefore, creating circuits based on QCAs is a straightforward use of this structure. [15]

Kunal Das and Debashis De (2011) investigated how the nanostructure of a basic computer is defined by quantum dot cellular automata (QCA). When designing high-speed computers, it serves as a substitute for CMOS technology. The fundamental logic of QCA is the logic state that measures the polarity of the electrons in the cell rather than the voltage level. Initially, developers constructed the Majority Voter (MV) when designing logic circuits. However, utilising MV alone made designing large logic circuits inefficient. There had been numerous suggestions for creating a QCA logic gate. This study focuses on several useful nanostructures, efficient design of the Nand-Nor Inverter (NNI), decreased size and design of and-Or Logic and AOI, as well as logic synthesis utilising proposed gates. We implement the NNI using 3×3 tile structures. We examine the QCA fault on the suggested gates and outline the acceptable level of defect tolerance. We outline the usefulness of the structures suggested in this study in QCA and discuss their potential application in creating ordinary functions. [16]

According to Singhal and Rahul (2011), the semiconductor industry appears to be approaching a point where difficulties related to power density and physical geometry may make device fabrication impractical. A novel nanotechnology called quantum-dot cellular automata (QCA) has promise for producing even more dense integrated circuits with low power consumption and high frequency capabilities. Instead of flowing to the electrons in a wire, QCA technology uses electrostatic interaction between the electrons to propagate the signal. A QCA cell, which encodes binary information using the relative positions of its electrons, is the fundamental component of QCA technology. One can use a QCA cell as logic or as a wire. An electric field, phase-shifted and produced on a layer other than the QCA cell layer, controls the directionality of the signal flow in QCA. We refer to this procedure as the clocking of QCA circuits. The semiconductor industry has greatly benefited from the logic realisation of regular structures like PLAs because of their easy logic mapping, behavioural predictability, and manufacturability. Regular structures in QCAs would provide a uniform QCA clocking structure in addition to these advantages. The clocking structure holds significance as the creators of QCA technology suggest fabricating it using CMOS technology. The design execution in detail and the comparative analysis of logic realisation utilising regular structures—that is, Shannon-Lattices and PLAs for QCAs—are presented in this thesis. As part of this research, a software programme was created that, given an input macro-cell library, automatically creates entire QCA-Shannon-Lattice and QCA-PLA layouts for single-output Boolean functions. Additionally, throughput and latency formulas for the new QCA-PLA and QCA-Shannon-Lattice design implementations were developed. Simulating the tool-generated layouts using QCADesigner confirmed the accuracy of the equations. A brief design trade-off analysis between the unstructured custom layout in QCA and the tool-generated regular structure implementation is shown for the full-adder circuit. [17]

S. Lakshmi Karthigai and G. Athisha (2010) discuss the many logical structure types based on quantum dot cellular automata (QCA) design. In nanotechnology, the QCA presents a novel paradigm for transistorless computing. Compared to transistor-based technology, it has the potential for attractive qualities, including faster speed, smaller size, and lower power consumption. By using the benefits of QCA, we may create intriguing computational architectures. The majority gate and the inverter are the two fundamental logic components of this technology. We use the fundamental components to create the additional logical structures. Instead of employing a 7-cell inverter, we have used a 2-cell inverter to create the logical structures here. Using this technique can lower the hardware requirements for a QCA design. The structures are designed and simulated using QCADesigner. A tool for designing and simulating quantum dot cellular automata is the QCA designer. Additionally, provided are the standard functions and their accompanying simplified majority expressions. [18]

Currently, researchers are investigating Quantum Cellular Automata (QCA) as a potential replacement for CMOS VLSI, as explored by Michael Thaddeus Niemier (2004). Researchers have examined some basic logical circuits and devices, but little to no work has been done on the architecture for systems of QCA devices. When taking into consideration systems of QCA devices, this work shows one of the earliest such initiatives. A team of researchers created a straightforward yet comprehensive processor dataflow solely in QCA. Moreover, methods for modelling circuits and designing floors have been created. The proposed dataflow potentially has smaller dimensions compared to the end of the CMOS curve, with remarkable size projections. Coverage includes size and power forecasts, real designs, floor planning strategies, simulation approaches, and fundamental QCA device physics. [19]

We propose a range of circuit designs for quantum dot cellular automata (QCA) that utilize the so-called coplanar crossover, based on Fabrizio Lombardi et al. (2004). The chart shows clear connection wire crossings, indicating the democratic majority of QCA. Longer voting and polling times achieve this. Rapid and accurate thermal efficiency comparisons are possible with BN simulators. Researchers illustrate numerous collinear transition designs (QCA) using nanotube integral pictures. [20]

CONCLUSION:

We looked at the history of QCA innovation. The process of constructing both combinational and sequential network designs is well documented. A large body of research has been dedicated to characterizing defects in various QCA components and evaluating the effects of these problems at the part of the circuit. The effects of flaws on QCA gates and inverters, as well as fault theories and methods for characterizing imperfections, are discussed. The difficulties of testing are discussed.

REFERENCES:

1. Jadav Chandra Das, Debashis De (2020). Reversible priority encoder design and implementation using quantum-dot cellular automata, IET Quantum Communication, 1(2): 72-78.

2. Hani Alamdar, Gholamreza Ardeshir, Mohammad Gholami (2020). Phase-frequency detector in QCA nanotechnology using novel fip-fop with reset terminal, International Nano Letters, 1-8. URL: https://doi.org/10.1007/s40089-020-00300-2

3. Syed Umira R Qadri et al. (2019). Design and implementation of cryptographic element with low power dissipation in QCA, 8(1): 96-106. https://doi.org/10.1680/jnaen.18.00013

4. Harshitha S., Dhanush T.N., Premananda B.S. (2019). A Novel QCA based Compact Scan Flip-flop for Digital Design Testing, International Journal of Engineering and Advanced Technology, 9(1): 6681-6686.

5. Md. Abdullah-Al-Shafi, Rahman Ziaur (2019). Analysis and modeling of sequential circuits in QCA nano computing: RAM and SISO register study, Solid State Electronics Letters, 1(2): 73-83. https://doi.org/10.1016/j.ssel.2019.11.004

6. Ismail Gassoumi, Lamjed Touil, Bouraoui Ouni, Abdellatif Mtibaa (2019). An Efficient Design of DCT Approximation Based on Quantum Dot Cellular Automata (QCA) Technology, Journal of Electrical and Computer Engineering, vol. 2019, Article ID 9029526, 11 pages, 2019. https://doi.org/10.1155/2019/9029526

7. Shiv Bhushan Tripathi, Aron Narzary, Rahul Toppo, Mrinal Goswami (2018). Designing Efficient Configurable QCA Nano Circuit for Morphological Operations in Image Processing, Journal of Physics Conference Series, 1039(1):012028, 1-6. DOI:10.1088/1742-6596/1039/1/012028

8. Radhouane Laajimi (2018). Nano architecture of Quantum-Dot Cellular Automata (QCA) Using Small Area for Digital Circuits, Advanced Electronic Circuits - Principles, Architectures and Applications on Emerging Technologies, DOI: 10.5772/intechopen.72691.

9. A. Rezaei (2018). Design and Test of New Robust QCA Sequential Circuits, Int. J. Nanosci. Nanotechnol., 14(4): 297-307.

10. B.S. Premananda; U.K. Bhargav; Kaza Sai Vineeth (2018). Design and Analysis of Compact QCA Based 4-Bit Serial-Parallel Multiplier, International Conference on Electrical, Electronics, Communication, Computer, and Optimization Techniques (ICEECCOT), Msyuru, India, 2018, pp. 1014-1018, doi: 10.1109/ICEECCOT43722.2018.9001619.

11. Zahid Shakee, Gh Mohammad Wani, Mehboob Ul Amin (2017). Design and Implementation of Efficient Combinational Logic Circuits with Minimum Area and Circuit Complexity Using Quantum- dot Cellular Automata (QCA), International Journal of Science and Research, 6(1): 115-120.

12. Abilash. B et al. (2015). Design of an Area Efficient Adder Using Minority Gates in QCA, International Journal of Innovative Research in Computer and Communication Engineering, 3(5): 3860-3867.

13. Chabi, Amir Mokhtar et al. (2014). “Efficient QCA Exclusive-or and Multiplexer Circuits Based on a Nanoelectronic-Compatible Designing Approach.” International scholarly research notices vol. 2014 463967. doi:10.1155/2014/463967

14. Mohammad Rafiq Beigh, Mohammad Mustafa, Firdous Ahmad (2013). Performance Evaluation of Efficient XOR Structures in Quantum-Dot Cellular Automata (QCA), Circuits and Systems, 4(2): 147-156.

15. Mohsen Hayati, Abbas Rezaei (2012). Design and Optimization of Full Comparator Based on Quantum-Dot Cellular Automata, ETRI Journal, 34 (2): 284-287.

16. Kunal Das, Debashis De (2011). A Study on Diverse Nanostructure for Implementing Logic Gate Design for QCA, International Journal of Nanoscience, 10 (1-2): 263-269.

17. Singhal, Rahul (2011). Logic Realization Using Regular Structures in Quantum-Dot Cellular Automata (QCA). Dissertations and Theses. Paper 196. https://doi.org/10.15760/etd.196

18. S. Karthigai Lakshmi and G. Athisha (2010). Efficient Design of Logical Structures and Functions using Nanotechnology Based Quantum Dot Cellular Automata Design, International Journal of Computer Applications, 3(5): 35-42.

19. Michael Thaddeus Niemier (2004). Designing Digital Systems in Quantum Cellular Automata, Thesis, Masters of Science in Computer Science and Engineering, University of Notre Dame.

20. Mehdi Tahoori, B. Jing Huang, Mariam Momenzadeh, Fabrizio Lombardi (2004). “Testing of Quantum Cellular Automata”, IEEE Transactions on Nanotechnology, Vol. 3, No. 4, pp.432-442.