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# Towards Physical Implementation of Quantum Computation

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## ABSTRACT

The future of computational speedup is no longer in the integrated circuits but in quantum phenomena. The emergence of Peter Shor's factoring algorithm resulted in a renewed interest in the field of computing. This paper focuses on the implementation of quantum computing from the hardware perspective by reviewing literature on the various technical requirements involved in the physical implementation of quantum computation. The David Divienzo criteria were examined as a necessary but not sufficient requirement in the implementation of quantum computing. The structure of existing quantum computer prototypes implemented by D-wave, Intel, Google, and IBM was also discussed. The paper also considered the significant advantages that quantum computers have over classical systems. The popular quantum algorithms and quantum gates were studied. Some examples of implementation of quantum computers using trapped ion, superconducting qubits, nuclear magnetic resonance, and quantum dots were also explored.

**Key words:** quantum computation, entanglements, factoring algorithm, superposition, trapped ions.

## 1. INTRODUCTION

Quantum computer is not yet in the common market for sale, but researchers are inching closer to a universally acceptable quantum computer [1]. Quantum computing denotes a technology that relies on quantum phenomena such as entanglement and superposition for their computation [1]. The reversibility of computations is the major catalyst for research into quantum computing [2]. The great pioneers and visionaries, Richard Feynman, Yuri Manin, and others who pointed the way towards quantum computation were inspired by the belief that quantum computers had the potential to perform great computations where classical machines cannot [3]. Over the years, the US government, China, and some other interested nations have supported researchers in the quantum computation for both civil and national security reasons [4]. Research has shown that a successful implementation of large-scale quantum computers will be able to execute certain tasks asymptotically more quickly than any classical computer systems [5].

Currently identified bottlenecks with the implementation of quantum computation include sensitivity to its interaction with the environments, errors which can be internally or externally induced, constraints on state preparations, etc.

This paper presents the basics of quantum computations, discusses the processes involved in its physical implementation, and examines technologies proposed for the actualization of quantum computing and possible limitations.

The processes involved in the quantum computing implementation includes the quantum algorithm design and error-correcting codes, the architectural design of the system [6], the implementation of more reliable quantum devices, with consideration to the DiVicenzo requirements on quantum implementation.

## 2. LITERATURE REVIEW

### 2.1 Background and Progress of Quantum Computation

The early computers were huge, expensive and usually requires more power in terms of its operation, today's computer systems are much reduced in terms of size, less expensive and more powerful as a resultant effect of improvement in computer software, hardware, and architecture [1]. The second and third generations of computers used transistors and Integrated circuits respectively as key components. The Integrated Circuit (IC) is a combination of different transistors via a metal layer on the silicon surface forming a complete circuit

Gordon Moore in 1964 observed that the numbers of transistors on IC has been increasing exponentially with time, twice in number roughly every year. Moore predicted that IC manufacturing technology will witness continuous improvement with the exponential growth in the number of transistor per IC. This law for IC could be termed as a virtuous cycle where improvement in technology resulted in an exponential increase in revenue, enabling reinvestment in research and development, evoking new talents to assist innovations and move the technology to another level [1].

Although Moore's law brought a lot of progress and innovation into classical computing over several decades, it is clear that this trend can't be continued due to physical limitations and the finite size of world markets; it is against this backdrop that propels the emergence of theory and prototype on quantum computing.

Quantum computation has been adjudged by a large number of people as a potential future alternative in dealing with high complexity problems by applying the different computational models. Classically intractable problems that exist in areas such as Encryption and Cyber security, financial services, supply chain logistics, etc. can be solved using quantum computation. Peter Shor in 1994 showed a practical example of how a quantum computer can factorize a large number exponentially faster than a classical computer. Technologies such as Trapped ion and Superconducting qubit have advanced in the implementation of quantum computation.

### 2.1.1 Basic Principles of Classical and Quantum Computation

Classical computers operate on a sequence of binary values known as bits with a possible value of either 0 or 1, these kinds of computers perform varieties of the task such as word processing, computations, image processing, etc through the manipulations of these bits.

Quantum computers operate on a sequence of quantum bits known as qubits. A qubit may hold a state zero or state one or a superposition of these two states. A quantum computer operates by controlling these qubits, i.e. by transporting these qubits between memory and logic gates.

### 2.1.2 Definitions of Some Key Quantum Principles

**Superposition:** when a quantum system can exist in its two states at once, the quantum system is said to exist in a superposition state; that is, the linear combination of the two states (a situation where a qubit is in a state of a certain amount of 0 and a certain amount of 1), this can be denoted mathematically as $\alpha_o|0> + \alpha_1|1>$ where $\alpha_o|0>$ represents the up spin and $\alpha_1|1>$ represent the down spin [25]. The coefficient $\alpha$ is referred to as the amplitude and these coefficients that define the amount of 0 and 1 in a qubit are complex numbers denoting that it contains real and imaginary parts.

**Entanglement:** This concept is one of the most powerful phenomena in quantum computation, it refers to the ability of individual quantum particles to be linked together as a single entity such that measurement in one affects the other even if they are far apart at different locations.

**Coherence:** A quantum state is said to be coherent when each of its states can be represented by a set of complex numbers, coherence is necessary for the quantum system to exhibit features such as entanglement, superposition [1]. Quantum state's interaction with the environment causes gradual decoherence. Decoherence refers to a loss of quantum's coherence properties, this is still a challenge in the physical realization of quantum computation

**Quantum Teleportation:** The feature of quantum computation that refers to the process whereby information can be transmitted from previously entangled quantum states without the movement of these states.

### 2.1.3 Classical Computation in Comparison to Quantum Computation.

Though the development of quantum computers will pose greater tasks, knowledge is obtained from the implementation of classical computers that cannot be ignored. Concepts used in the implementation of classical computers can be adapted for the implementation of its quantum counterparts.

One of the key differences between classical and quantum computation is in the area of memory, in classical computing, data is easily stored permanently and also transferred with ease, disk memory can keep data for a longer period unlike the case of a quantum computer whose data only last whilst the program is running[11]. There exist numerous reasons for this, integral weakness originates from the no-cloning theorem which states that the quantum information cannot be copied unlike in the case of classical information [12], hence prolong state preparation is performed multiple times as there is no way of creating multiple data. Quantum states are fragile and naturally decay, thus, it is extremely hard to preserve quantum information for a very long time.

In the course of quantum computation's progression, quantum memory could be more practical and this will be very valuable as many large scale implementation of quantum computation will depend on this factor. Another area of comparison between classical and quantum computation includes data security, the capacity of computation, and capability to accept noise, with the successful implementation of quantum computing. While quantum computing provides the highest form of security against attack, it requires a noiseless channel for successful communication.

## 2.2 Related Works

The necessary conditions for the successful implementation of quantum algorithms on the quantum computers are presented in [8]. The paper offered some basic concepts in the processing of actual information and evaluation of the most promising techniques where experimental progress has been performed for the implementation of quantum computation.

DiVincenzo [3] postulates the requirements for the physical implementation of quantum computation, popularly known as Divicenzo requirements. These requirements about some atomic physics concepts (such as quantum optics, spectroscopy, superconducting electronics, etc.) in realizing quantum computation were explained.

The author in [11] gave a quick review of the principle and history of quantum computing and quantum mechanics. The paper also dealt with quantum algorithms, quantum gates, and its implementation were discussed.

The article [19] discussed the current and future potentials of quantum computing and also stated the problems involved in the realization of quantum computers. The work also stated how quantum error correction can be used in tackling these issues and how Noisy Intermediate-Scale Quantum (NISQ) will be available soon. NISQ refers to the size of the quantum computers which will be available in a few years.

Article in [33][34] shows the structure of a quantum computer, the intersection between quantum and classical computers, the hardware and software requirements of the quantum computer system. Study on qubits, gates, and algorithms facilitated the understanding on the technicalities of the quantum computer, limitations to implementation, and the way forward.

## 3. ELEMENTS OF QUANTUM COMPUTATION

Quantum computers solve different computational problems using quantum algorithms, among the most popular ones are Shor's factorization algorithm and Grover's algorithm. Whereas the former is applied in factorizing large numbers, the latter is applied in searching of large unstructured databases. This algorithm's application is needed to be mapped into a single operation and this operation is required to be factored into a sequence of few-qubit operations known as gates [8].

### 3.1 Quantum Algorithms

The Shor's and Grovers Algorithm are described below as follows:

**Shor's Algorithm**

Peter Shor, a mathematician of American origin in 1994 presented an algorithm for prime factorization. It is important to note that there is yet no algorithm for prime factorization in the high-speed classical computers making it virtually impossible for the current RSA code to be cracked.

Shor's Factorization Algorithm
Step 1: Choose a suitable integer a such that $a < N$
Step 2: Evaluate $f = \gcd(a, N)$. If $f \neq 1$, then f is a factor of N. else goto step 3
Step 3: Obtain the smallest possible integer r that has a remainder 1 when dividing $a^f$ by N, i.e., $a^f \text{ Mod } N = 1$
Step 4: If any of $\gcd(x^{a/2} - 1, N)$ or $\gcd(a^{r/2} + 1, N) \neq 1$ then it is a factor else goto step 1.

**Grover's Algorithm**

Grover's algorithm is a very useful algorithm that can be applied for a search operation in a large unstructured database; quantum computers which ordinarily will deal with large arrays of data will require this kind of algorithm. The computational complexity of the search is linear i.e. 0(n) if Grover's algorithm is used, the computational complexity can reduce to $0(\sqrt{n})$ which will produce a great difference if large numbers of data are involved.

| Classical computation vs. | quantum computation |
|---|---|
| 0(n) | $0\sqrt{n}$ |

Let N represent the number of elements that the search operation will be carried out on. N also denotes the dimension of the state space search that is to be worked on. A key operator called Grover's operator or Grover's diffusion operator in Grover's algorithm is defined as follows:

$$G = (2|\psi\rangle\langle\psi| - I)O$$

where

$$|\psi\rangle = \frac{1}{\sqrt{n}}\sum_{x=0}^{n-1}|x\rangle$$

$|\psi\rangle$ is obtained by applying Hadamard transform to the qubits to ensure the equal superposition of the basic states while Grover operator is subsequently applied to enable a successful search operation, The Grover operator is achieved in four steps

Step 1: Initial state requirement: $|0\rangle^{\otimes n}$, ensure the element is requested
Step 2: Apply Hadamard transform on the initial state creating equal superposition of the states $H^{\otimes n}|0>^{\otimes n}$ for
Step 3: Apply the Grover operator G and iterate for $(0\sqrt{N})$ times
Step 4: measure the system

Other Quantum Algorithms includes:

- Deutsch–Jozsa algorithm
- HS Algorithm
- Adiabatic Quantum Algorithm.

### 3.2 Quantum Gates

To design and implement any computer system, a circuit is required to perform computation. Circuits in classical computers are designed using Boolean algebra which consists of a sequence of 0's and 1's. classical computing devices perform computation by manipulating the bits- transporting the bits back and forth the computer memory and logic gates, some of the logic gates that exist in classical computers include the NOT, OR, AND and NAND. Early researchers in the field of quantum computation have proposed the theory on quantum gates different from logic gates in classical machines based on the concept, but the proposed gate can simulate the classical logic gates.

The unitary matrix determines the computation of qubits which varies the state at a different point in time. The result of the computation is realized through measurements from the projections on base states. The result obtained from the measurement after computation is defined as the probability amplitude which indicates the square of the probability of the output, thus the outcome of the computation performed by the quantum gate is a real number.

The above procedure can be outlined as follows:
Initialize qubits as the computational base, Apply the Unitary transform U to qubits and Measure the base state and compute the probability amplitude.

Thus, the mechanism of quantum gates is displayed in Figure 1.

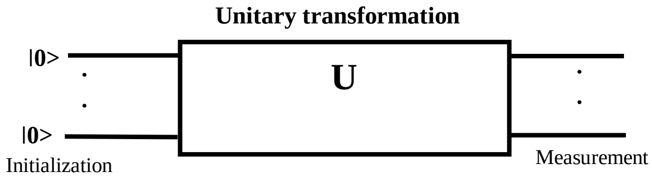


**Figure 1:** Unitary Transformation [13]

Figure 3.1 shows that the unitary transformation needs to be applied to the quantum gates. This can be mathematically expressed in a matrix form. Let a represents the input qubits, b represents output qubit and U represents the unitary matrix.

Thus, when a unitary transformation is applied on the input qubit, the output qubit can be expressed with the equation below

b = Ua

Unitary transformation possesses reversibility characteristics, thus a quantum gate has of an equal number of inputs and outputs [13]. The unitary operator U is defined on the Hilbert space for n cubits=$C^{2n}$ as follows:

Where

$$\sum_{k=0}^{2^n-1} u^*_{ki}u_{kj} = \delta_{ij} \qquad \sum_{=0}^{\;-1} |i\rangle u_{ij}\langle j|$$

Thus, we can observe that unitary transformation is pivotal to quantum computing and quantum gate function as a device in achieving this. The distinguishing features between the Boolean function and the unitary operator include parallelism, superposition, and reversibility.

Unitary matrix U represents the quantum gates computation, the computation is reversible for time since UU∗=U∗U=E holds. In reversible computation, inputs can be reconstructed from the output, this is not possible in non-reversible computations (Logic gates in classical computers).

### 3.2.1 Useful Quantum Gates

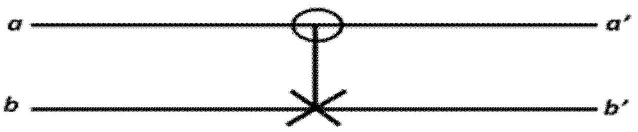
Different useful quantum gates including the Hadamard gate, CNOT gate, Tofolli gate, Pauli-Z gate, and NOT gate are described as:

Hadamard gate: a quantum gate with a single-qubit operation that maps the basis states |0> and |1> into $\frac{|0> + |1>}{\sqrt{2}}$ and $\frac{|0> - |1>}{\sqrt{2}}$ respectively, thus transform the basis states into an equal superposition of its states.

The unitary matrix for its computation is expressed below:

$$U_{Had} = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

C NOT gate: Known as a controlled-NOT gate. The NOT gate is activated if the controlled input is "1' else it is not activated since the activation of NOT gate is determined by the controlled input.

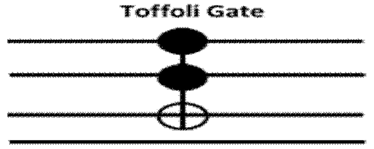


The Unitary matrix for its computation is represented below:

$$U = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Toffoli gate (CCNOT gate)

CCNOT (Controlled Controlled NOT ) gate is a 3-qubit gate system that switches the bits for states where the first 2- bits are one i.e. |110> will change to |111>

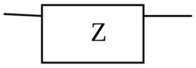


The unitary matrix for tofolli gate's computation is represented below

$$U = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix}$$

Pauli-Z gate

This is a single qubit rotation through $\pi$, maps |0> to itself and |1> to |-1> having a notation



The unitary matrix to represent Pauli-Z gate is displayed below:

$$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

### 3.3 Quantum Error Correction

Superposition is one of the quantum computing phenomena highly susceptible to interference and perhaps, one of the major difficulties in the realization of quantum computation. In addition to dissipation and decoherence which refers to the loss of superposition properties, the quantum system can encounter errors during their coupling with the environment, also when gate operations interfere with the computing process, although the cumulative effect of these errors can be damaging, it can be reduced through error correction. The process whereby a quantum computation error is reduced to the barest minimum produces a fault-tolerant quantum computation.

Error correction depends on redundancy, one qubit state can be written in the following form

$\propto |0> + \beta|1>$

The highly entangled three-qubit state is written as $\propto |000> + \beta|111>$

This is realized by starting $(\propto |0> + \beta|1>) \otimes |0> \otimes |0>$ and applying the CNOT on the last two zero qubits and having the first qubit as the control qubit. Size of the qubit Hilbert space is enlarged from 2 to $2^3$ with the usage of 3 qubits if at maximum, one of the spins flips, the position of the flip can be easily located by projecting the state on four orthogonal states, which are:

$$P0 = |000><000| + |111><111|$$

$$P1 = |000><000| + |011><011|$$

$$P2 = |000><000| + |101><101|$$

$$P3 = |000><000| + |110><110|$$

The outcome allows the flipped qubit and unflipped qubit to be identified and this enables easy error correction to be performed on the unflipped qubit. This doesn't disrupt actual superposition since it is not known if spins occur.

### 3.4 DiVincenzo Requirements for Implementation of the Quantum Computation

David DiVincenzo, in the year 2000 proposed the necessary criteria to implement a quantum computer. The study presented five requirements in the implementation of quantum computation. Besides, two requirements for quantum communication were identified. These five criteria include Measurable, Universal, Scalable, Initialize-able, and Coherent (MUSIC) [34]:

**Measurable:** The output string of a quantum computer should be readable qubit-by-qubit. This refers to the ability to measure the quantum states of each qubit individually. For instance, if a quantum state is in 0 or 1, there should be a physical process that allows this state to be determined at any point in time through measurements. This is quantified by the readout error. Combining this with the relaxation time, coherence time, and the gate errors form the basic metric in evaluating qubit design. All these must be observed with a high degree of accuracy.

**Universal:** The quantum logic gates should be universal such that any arbitrary quantum algorithm can be composed as a sequence of their logic gates. This requirement is at the heart of quantum computing and must be achieved to maintain quantum parallelism. A single qubit gate refers to a bunch of unconnected superposition which could be called memory register. A state where the products of different quantum states cannot be taken comes with zero entanglements and does not have the capability of exponential speedup. Universal quantum gates permit entanglements among different qubits in different states.

**Scalable:** The number of qubits and logic gates can be increased so efficiently that the cost does not outweigh the quantum effect. The first condition requires a system with a well-known collection of qubits. A qubit is simply a two-state quantum system which is like the ground and excited states of an atom or polarization of a single photon, this requires the selection of two quantum states to be used as |0> and |1>. One of the key features of quantum computation is superposition, this is simply the linear combination of up spin and down spin. Mathematically, it can be represented as $\alpha_o|0> + \alpha_1|>$ where $\alpha_o|0>$ represents the up spin and $\alpha_1|>$ represent the down spin. The coefficient α is referred to as the amplitude. Below is the general equations describing a 2-qubit system:

$|\psi_0> = \alpha_0|0> + \alpha_1|1>$, $|\psi_1> = \beta_0|0> + \beta_1|1>$.

$|\psi_0>|\psi_1> = \alpha_0\beta_0|00> + \alpha_0\beta_1|01> + \alpha_1\beta_0|10> + \alpha_1\beta_1|11>$ so the new quantum states has 4 computational basis vectors, namely |00>, |01>, |10>, |11>.

**Initialize-able:** Before computation, the qubit string can be set up to be in the zero ' |0〉 'state. It is important to have well-known qubits and as well capable of initializing qubits into a pure state in the state space. The second criterion emerges from the straightforward computing requirement that registers should be initialized to a single state before the application of the quantum algorithm. The second reason for this initialization is that quantum error correction requires a continuous, new qubits supply in a low entropy state (like the |0〉 state) not just for initial supply but also a continuous supply of 0s. This is a problem for many proposed implementations.

**Coherent:** Decoherence time is much longer than the gate operation time: This addresses decoherence which is one of the major problems in quantum computation as a qubit is very delicate. This refers to the ability of the quantum gate operations to perform before the system fully decohere. To avoid this problem, the system should have the ability to keep its superposition state for a long time. Noise, heat, electromagnetic fluctuation, vibration, or particle spin from the surrounding environment or the control line corrupts the information of a qubit [38]. The factors involved in the measurement of the quality of quantum computing design include Relaxation time, coherence time, readout errors, and gate errors.

The above 5 requirements are sufficient for straightforward computation alone. Many types of information processing tasks involve not just computing but also quantum communication. Quantum communication means when intact qubits are transmitted everywhere. This added more features, which must be carried out by physical devices. Two additional items were introduced as follows:

1. The ability to interconvert stationary and flying qubits.
2. The ability to faithfully transmit flying qubits between specified locations

## 4. STRUCTURE OF QUANTUM COMPUTER.

Engineering principles require that machines are broken down into functionally similar parts and each part is given its due attention [34]. In the effort to develop a universally acceptable quantum computer, researchers have partitioned the quantum computer system into five major layers with disparate types of processing [33][35]. This strategy applies to renowned organizations such as IBM, Intel, and Google. These layers beginning from the uppermost are The application layer, the classical layer, the digital layer, the analog layer, and the quantum processing layer. The digital, analog, and quantum processing layers constitute the quantum processing unit (QPU) and these layers are strongly interdependent to one another [33].

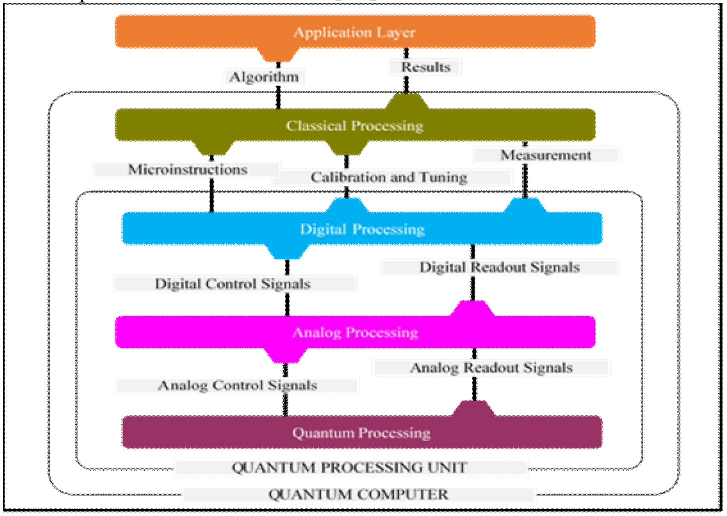


**Figure: 2:** The layered components of a quantum computer [33]

**Application Layer**: The application layer does not form part of the quantum computer but a vital chunk of the whole system. It is concerned with all that are required to design appropriate algorithms such as programming environment, an operating system, user interface et al. Algorithms created in the application layer can be fully quantum or both quantum and classical. The Application layer is designed to be independent of the underlying hardware [33] [35].

**Classical Processing Layer:** This performs three fundamental tasks as follows:

1) Enhancement of the quantum algorithm being run and as well assembles it into microinstructions similar to the CPU operation of the integrated circuits-based computers.
2) Handling of quantum state measurements given back by the succeeding layers hardware. This might be returned to the classical algorithm for the final output.
3) Processes the calibration and tuning required for the subsequent sections.

Quantum processing unit: Starting from topmost, the three layers that constitute this layer are described below:

**Digital Processing Layers:** This layer converts microinstructions into signal pulses that enable them to interact with the qubits and to perform as quantum logic gates. The digital layer digitally defines what the analog pulse generated should be. It also returns quantum calculations output measurement to the preceding layer 'classical processing layer' to generate a final classical output.

**Analog Processing Layer:** This layer produces different types of signals directed to the qubits at the immediate succeeding layer. The signals are essentially voltage steps and sweeps, bursts of microwave pulse, modulates in phase and amplitude to execute the required qubit operation. The operations include the formation of quantum logic gates by connecting qubits and computation using the gates following a specific algorithm. A challenge is in managing signal generation for a practical quantum computer, from synchronization of signals at picosecond timescales to embedding information in the signals. These are the current research gaps that many researchers are aiming to fill.

**Quantum processing layer:** This is the area responsible for the manipulation of qubits using the quantum logic gates. This space does quantum computation alongside some level of error correction. This layer operates at a near-zero temperature unlike in digital-analog layers of present computers that mostly function at room temperature. A suitable mechanism is used to achieve the cooling effect. It is expected that the increase in the size of qubits will integrate all the electronics components of the three-layer into a packaged cryogenic chip.

The national academy of science, engineering, and Medicine proposes four planes to define the structure of the quantum computer, these are the quantum data plane, the control and measurement plane, the control processor plane, and the host processor plane [32] [37].

The Quantum Data Plane: This is similar to the quantum processing layer. It is the core of a quantum computer. This plane holds the qubits, the circuitry, and quantum logic gates or Hamiltonian control in an analog computer.

Control and Measurement Plane: This plane mediates between the analog and digital processing layers described above. The output of the analog processing layer derived from the data plane is converted to classical binary and vice versa. The quantum data plane operates on analog signals. Error correction and fault tolerance are very important in this phase as errors can magnify as the computation runs. The execution time of a quantum computer cannot exceed the time taken to actualize the accurate control signal needed to execute quantum computations.

Control Processor Plane: The control processor plane is responsible for the execution sequence that will be triggered for a given algorithm or computation. The execution itself is done by the control and measurement pane which is on the quantum data plane. The control processor plane is responsible for the error correction.

The Host Processor: This plane uses a conventional operating system and utilities for its algorithm selection and execution sequence. It provides the conventionally expected computing capabilities. It is a classical computer that interfaces between the users and the quantum unit of the quantum computer system.

## 5. IMPLEMENTATION OF QUANTUM COMPUTERS

Some of the approaches currently in use to implement quantum computers physically include Trapped-ion computation, Nuclear magnetic resonance, quantum dots, superconducting qubits, etc.

**5.1 Trapped-Ion Quantum Computation:** one of the most promising approaches in the construction of large scale quantum computation is trapped-ion quantum computation [23]. In this approach, ions or charged atomic particles that represent the quantum bits are trapped in a confined space using the electromagnetic field. Entanglement is realized using shared ions motional modes as a quantum bus. The highest precision in the implementation of quantum computers has been achieved using a trapped ion approach.

Ions are usually maintained in space with the usage of either penning or Paul trap. Penning traps are dynamic traps that actualize confinement in one axial dimension using a static electric field, also confinement can be actualized in quadrupole configurations, with two perpendicular radial directions using parallel static magnetic field while in Paul trap an oscillating electric field introduce a ponderomotive confining pseudo potential into or three dimensions.

When proper trap parameters are followed in conjunction with ultra-high vacuum conditions, an atomic particle can be held in these kinds of traps for a long time.

**Laser Interaction:** Trapped Ion quantum information processing employ resonant interaction with laser light at every stage of its implementation, lasers are introduced after trapping to produce coupling among the qubits states to achieve entanglements.

Laser Cooling is an essential ingredient in trap ion quantum information processing as it gives control over the motional states of ions and is implemented along with trapping [8]. It relies on the photon recoil or more generally, the mechanical effect of light in the photon scattering process which is caused by the spatial variation of the electric field. Doppler cooling and Sideband cooling are promising laser cooling techniques.

**Doppler Cooling:** This is a mechanism that can be used in trapping and slowing the motion of a small particle usually an atom, if laser light is tuned slightly below to the electronic transition frequency of an atom, as the atom moves towards the laser light, it acquires a photon through **Doppler Effect**. It is the initial cooling stage, it is actualized by exciting the atomic ion(s) on a strong transition of natural line width with the laser detuned to a slightly less electronic transition in a system's resonance frequency.

**Sideband Cooling:** After the initial cooling stage using dropper cooling, sideband cooling is applied to cool the atoms beyond the dropper cooling limit, potentially to their motional ground state. Quantum mechanical harmonic oscillator can be applied to a cold trapped atom if the rate at which the atom transits from an excited energy state to lower energy states is much smaller than the vibrational frequency of the trapped atom. The energy levels of the system can be resolved as consisting of internal levels each analogous to a ladder of vibrational states.

For further readings, refer to [23].

### 5.2 Quantum Computation Realization using Nuclear Magnetic Resonance

Nuclear Magnetic Resonance is a well-researched area and highly applicable in different fields of science such as chemistry and medicine and it is the first approach used in the implementation of quantum computing, this occurs when large numbers of atoms are immersed into the magnetic field at 0 frequency and subsequently exposed to magnetic field exhibiting high and low alternating frequencies.

Qubits are generated when spins inherent in electrons interact with a spin that takes place in its outer nucleus moving in parallel and anti-parallel fashion [13].

Gersenfield and Chuang, MIT Researchers in 1998 were successful in implementing a 2-qubits quantum computer. This is the first physically implemented quantum computer [14].

The approach used likened a molecule as a single computer whose state is decided by the direction of its spins [13]. Great benefits of this approach include easy scalability, long coherence times of the order of nanoscale [24]

**5.3 Quantum Dots:** These are tiny particles built-in semiconductor materials holding tiny covering of electrons generating spins of dots which could be up or down spins, the dots are confined in three-dimensional space. The dot's size is highly controllable during the process of fabrication, the first excited state and the ground has a greater energy difference between them when the dots are smaller [24].

**5.4 Superconducting Qubits:** One of the recent significant approaches in the implementation of quantum computers is the use of superconducting qubits. Superconductivity is a property that occurs in certain materials at low temperatures in which electrical resistance is nonexistent and removal of the magnetic flux field from the material is affected by the material.

It is highly considered based on its no resistance characteristics at low frequency [1]. Qubits for digital quantum computing, and simulation are most commonly fabricated from aluminum wiring, while superconducting qubits can be fabricated using the same design tools and fabrication equipment.

In an ideal scenario of superconductivity, the copper pairs formed from the interaction between electrons residing in the superconductor are insuppressible carriers of current and resistance will only occur by an operation that generates adequate energy that can break the pair, though the cooper pairs single-electron states consist of a distinct pairing gap which separates the states which at a low temperature rise above the thermal energy in the system.

Therefore, superconductivity is the most typical example of an observable quantum coherent system of degenerate electron gas. The rate of change of that phase gives the superconducting current the characteristics property of liquids with zero viscosity and thus flows without losing kinetic energy and bose-Einstein condensation of atomic or molecular gases are similar low-temperatures examples with overall phase coherence. A superconducting current can pass through small regions of an insulating substance by quantum tunneling, one way to achieve this is through the breaking of cooper pair during the process or by moving the cooper pairs from one superconductor to another through the thin insulating layer, this kind of motion of pairs of electrons makeup what is known as Josephson current and the junctions is called Josephson junction.

### 5.5 Charged Qubits

A simple setup can be prepared with a single Josephine junction and a pair of superconducting regions resulting in a loop by the application of a voltage source, to obtain what is being known as Cooper pair box. Usually, one pair of superconducting regions is of small size and is known as an island. The interesting angle is that although there exist numerous cooper pairs on the island, its electrostatic properties are capable of being controlled by a single copper pair. The system can be tuned such that, initially, there are zero excess cooper pairs on the island. The junction has capacitance $C_t$, and another ($C_a$) between the external circuit and the island. The Hamiltonian for the system is then

$$H = \frac{1}{2}E_c(n - na^2) - E_j COS\emptyset \quad , \quad E_c = \frac{(2e)^2}{c+c_g}$$

$$, n_g = \frac{c_g v_g}{(2e)}, E_j = \frac{1_c h}{2e}$$

Ve represents the external voltage applied across the system (Nakahara and ohmi 2008) and $n_e$ represents the cooper pair number of the island while n is limited to integer values.

### 5.6 Phase Qubits and Circuit QED

Phase qubit consists of a single Josephine junction and a current source which enables the two electrodes present in Josephine junction to be connected and move current through the junction. This provides a means of controlling the behaviour of the qubit.

Over the years there have been many circuit QED demonstrations involving many kinds of artificial atoms, circuit QED is artificial atoms obtained through a small-size combination of different electronic components forming a circuit through their connections. David J. Wineland and Serge Haroche introduced cavity quantum electrodynamics through their Nobel-winning invention, the invention allows individual particles to be manipulated and measured and still be preserved, this work served as step and motivation in the actualization of circuit quantum electrodynamics (circuit QED) [30].

## 6.CONCLUSION

With the volume of 0n-going research in quantum computing, a breakthrough is near. The DIvicenzo criteria is a necessary but not sufficient requirement for the implementation of quantum computing. Researchers have technically shown that these criteria can be met, however, when coupled, some factors influence the performance of the quantum computers. Beyond the physical implementation, the software architecture of the quantum computer is of importance to achieving a reliable quantum machine. Increasing coherence is essential in the implementation of large-Scale computation. Clever algorithms can lower the physical and engineering requirements to build useful and commercially viable quantum machines. The future will improve the understanding of quantum physics and its applications on the realization of quantum computers and quite possible, in the nearest future the implementation of large-scale quantum computation will be witnessed.

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