Understanding Quantum Computing

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***Abstract*— Quantum Computing- Unlocking the Power of Quantum Physics.Quantum computing is a revolutionary field in computer science that harnesses the principles of quantum physics to create computers with unparalleled processing capabilities. Therefore in this paper, I have tried to explain various aspects of quantum computing and some of the procedures involved in the quantum computing system.**

I. Introduction

A classical computing system works on the calculations and mathematics done in bits i.e in 0's and 1's. But it is at this stage where quantum computing starts getting different and unique from the classical computing system. Because in quantum computers *QUBITS* are used instead of bits. The value of qubit is never fixed on 1 or 0, every qubit is on the *SUPERPOSITION* of 1 and 0.

A. Superposition in Quantum Computing

Let's understand this with the help of a coin. A coin has heads and tails in the similar way a bit system has 1 and 0. But if we start spinning the coin then the coin is not in a steady state, so we can't say if it is a heads or tails.While a classical bit can be at one state i.e 0 or 1 at a single time or moment, a quantum Qubit can be at both the states at one time.So this is called as a qubit in its superposition.

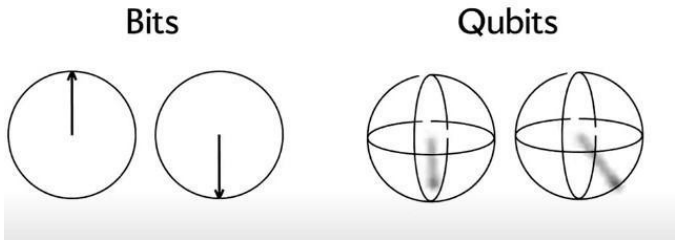

Fig. 1. Representation of Bits and Qubits in classical and quantum computing systems respectively.

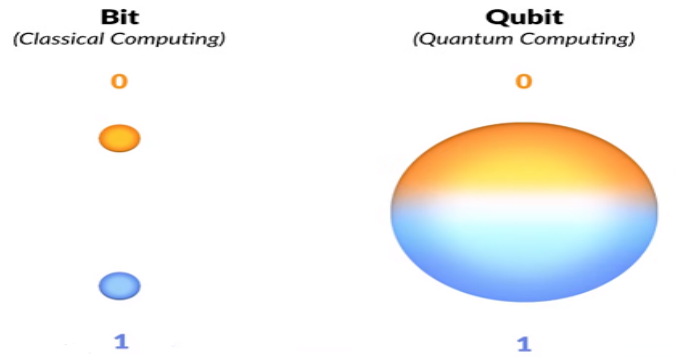

Fig. 2. Representation of Bits and Qubits in 0's and 1's.

Superposition is a fundamental principle in quantum physics. In nature, nothing is stable at a quantum level. Presence of several states at a single time can be called a superposition. But this superposition exists only until there is no external interference.Superposition ends at the very same moment when it is observed.

B. Computing in Terms of Qubits

In the world of computing , there can be a lot of things which can be done with the use of Quantum Qubits. Instead of a single Qubit when we consider two Qubits, we get 4 possibilities at one time. Similarly if we consider three qubits it turns out to be 8 possibilities.

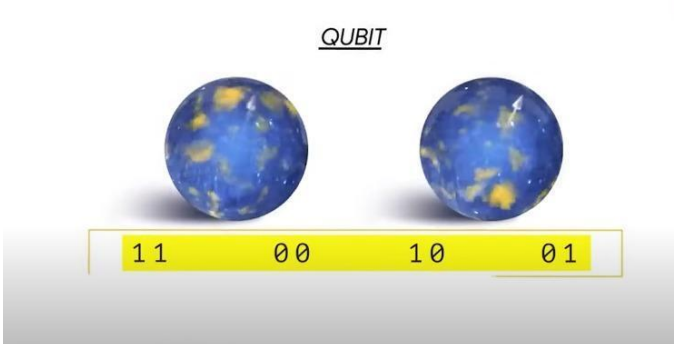

Fig. 3. Possibilities in 2 qubit computing systems.

Fig. 4. Possibilities in 3 qubit computing systems

This kind of growth in the no. of qubits and the no. of possibilities is known as *Exponential growth.* We can understand this with the formula $[P = 2^n]$where 'P' is the no. of possibilities and 'n' represents the no. of Qubits. Now imagine how much information a processor with 53 cubits can hold. The answer is 2^{53} states, which is 9007199254740992.

In 2019, GOOGLE presented their SYCAMORE Quantum Computer which according to them is processing with 53 Qubits.

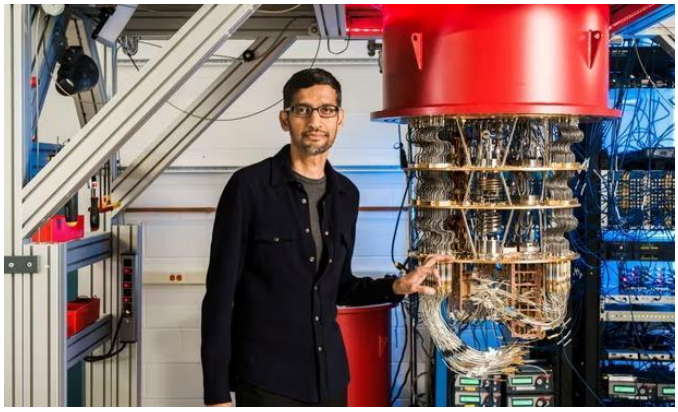

Fig. 5. Google's Quantum Computer SYCAMORE

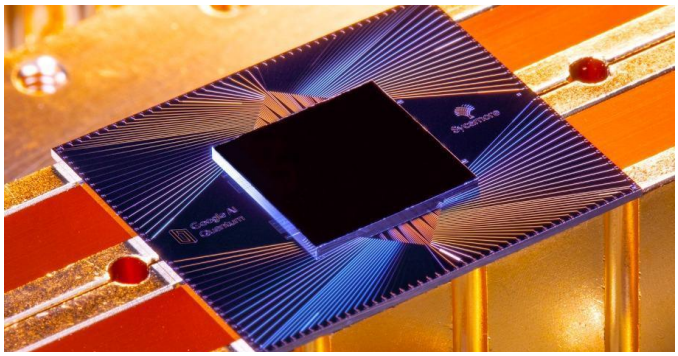

Fig. 6. SYCAMORE Quantum processing Chip

II. Procedures And Phenomenons

Quantum Computing involves many procedures and phenomena which are carried out with absolute precision and accuracy, which includes Entanglement, Quantum Interference, Electromagnetic Pulses and Quantum Decoherence.

A. Entanglement

Only the presence of Qubits in a Quantum system is not enough, one more crucial stage is Quantum Entanglement. The basic meaning of Entanglement in English is establishing connection between two things. Entanglement is a core concept in Quantum Mechanics. With the help of this we can connect any two objects. There is always an invisible connection between these two things.

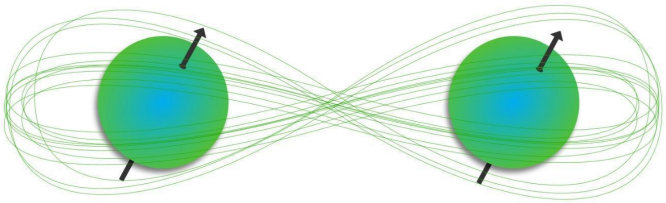

Fig. 7. Quantum Entanglement between two Qubits

If there is some instability in one object then the other gets disturbed. In Quantum computers when Qubits are entangled with each other, their states get matched to each other. The benefit of Entanglement is that this procedure forms a Mathematical Corelation between each qubit.

B. Quantum Interference

The next important procedure is Quantum Interference. With the help of Quantum Interference we can give the instability of superposition a direction. As we know Interference is a core topic in *WAVE MECHANICS* which includes destructive and constructive types of interference.

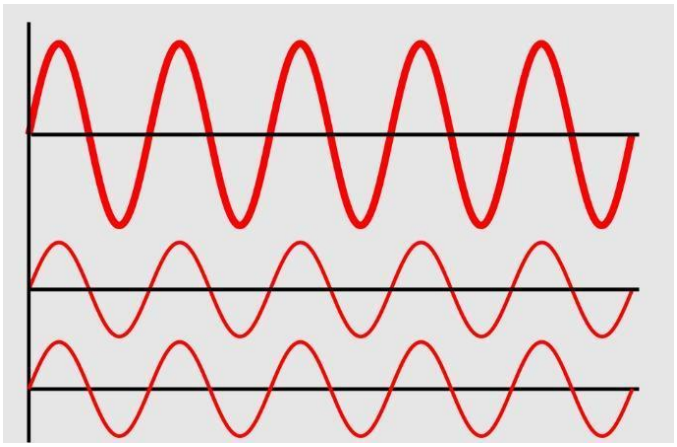

Fig. 8. Constructive Interference diagram

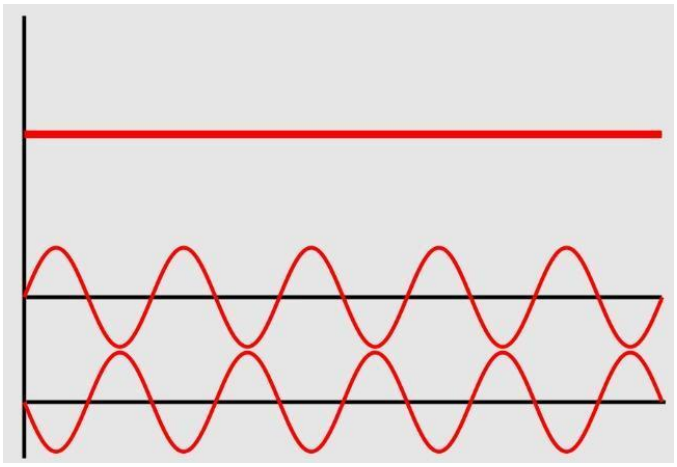

Fig. 9. Destructive Interference diagram

The same thing happens in Quantum Interference wherein with the help of interference some properties are escalated and some are diminished. Constructive Interference leads to the increase in the probability of correct solutions and Destructive interference reduces the probability of wrong solutions.

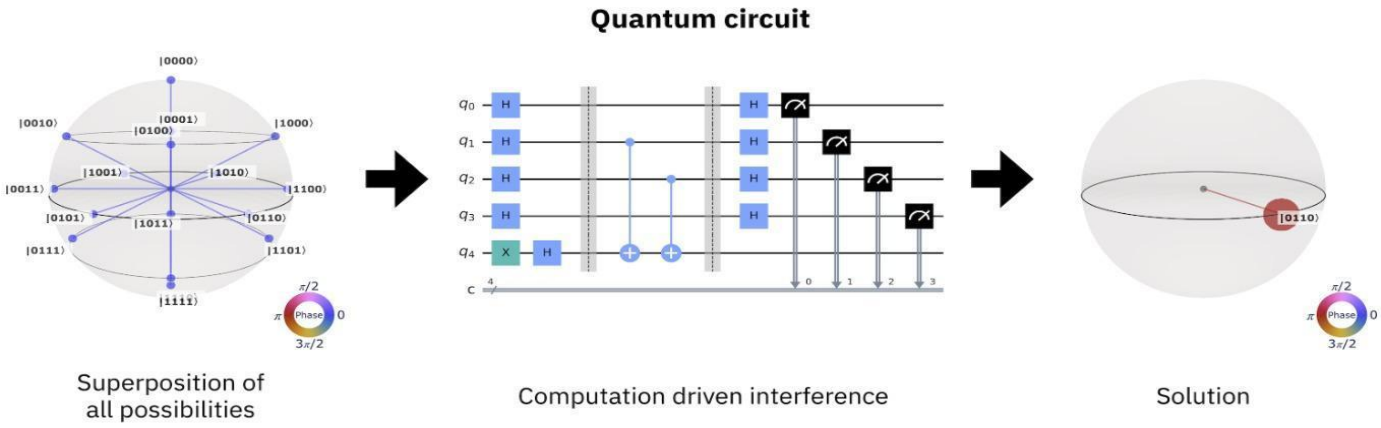

Fig. 10. Representation of a Quantum Circuit

C. Quantum Decoherence

In the case of Quantum Computing, external intervention or interference should be restricted. Because all the Qubits are connected in the Entanglement system therefore if any one Qubit is disturbed then the whole computation goes wrong. So this loss of *Quantum Coherence* or when the information of a quantum system is altered by the systems interaction with the environment is called the Quantum Decoherence.Quantum Decoherence is the most difficult problem or obstacle when it comes to Quantum Computing. To avoid this Decoherence the quantum computer is stored in a *DILUTION REFRIGERATOR* which only operates at *absolute zero temperature* that is ideally below 10mk(milli kelvin) or 0.01k. Such an ultralow temperature can be achieved by a Helium Dilution Fridge which creates cooling power by mixing Helium-3 and Helium-4 isotopes.

Fig. 11. Dilution Refrigerator for storing Quantum Computer

D. Electromagnetic Pulses

Now comes the most important part that is How interference is carried out in a quantum computer? At this point Electromagnetic Pulses come into action. There are many layers in a quantum computer which contain some vessels or tubes through which the electromagnetic pulses are sent.

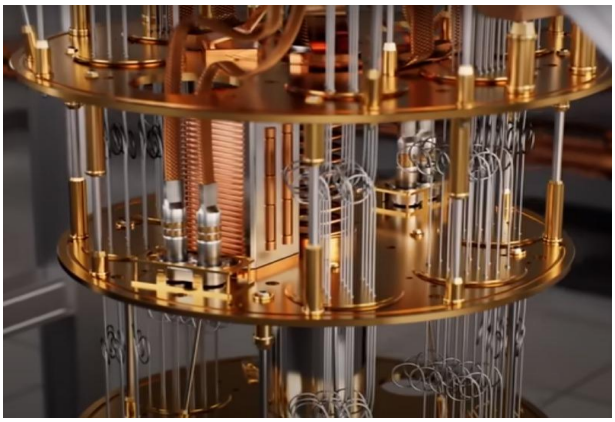

Fig. 12. Representation of tubes in the Quantum Computer

In any Quantum computer the temperature of every layer goes on decreasing as we move towards the bottom of the computer. And finally at the most bottom part of the computer A Quantum Processor is placed where all the Qubits are present.

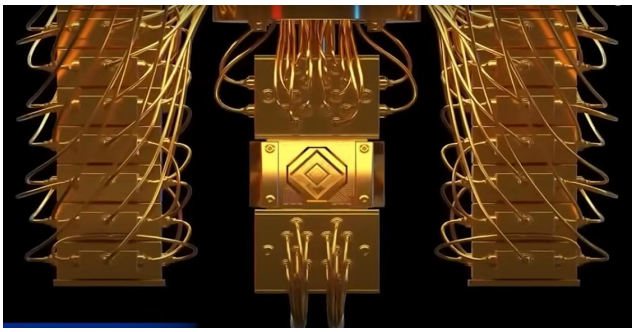

Fig. 13. Bottom part of the computer where processor is present

All the electromagnetic pulses are executed with a sequence of algorithms. And these pulses further manipulate the superposition of a Qubit without any decoherence. In an ideal Quantum Computer not only the no. of Qubits but also the quality of Qubits or how fault tolerant they are matters.

Fig. 14. Picture of a quantum computer system

III. Latest Happenings And Research Growth

Currently Scientist and Researchers are mostly interested in designing out more high quality Qubits and good error correction schemes. If these two obstacles are tackled, then it will be efficient enough for us to get the most out of quantum computers.

A. Research Trends in Quantum Computing

In the near future, it is likely that quantum computing will continue to be developed for specific applications such as optimization, machine learning and cryptography. As discussed above Researchers are also working on developing more stable and reliable Qubits, which are the building blocks of quantum computers.

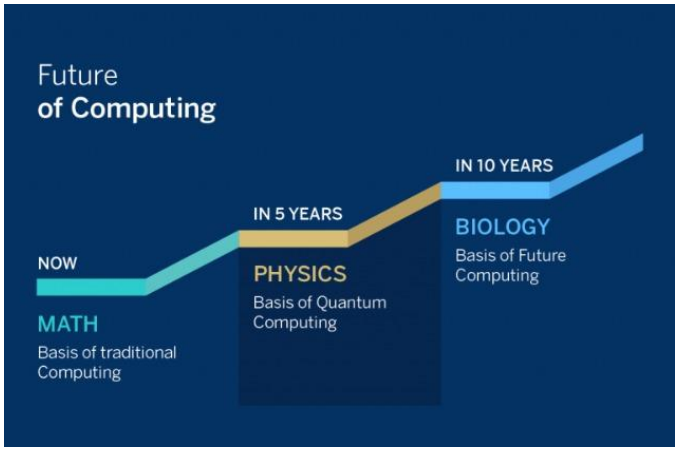

Fig. 15. Graph representing Growth in Quantum Computing Sector

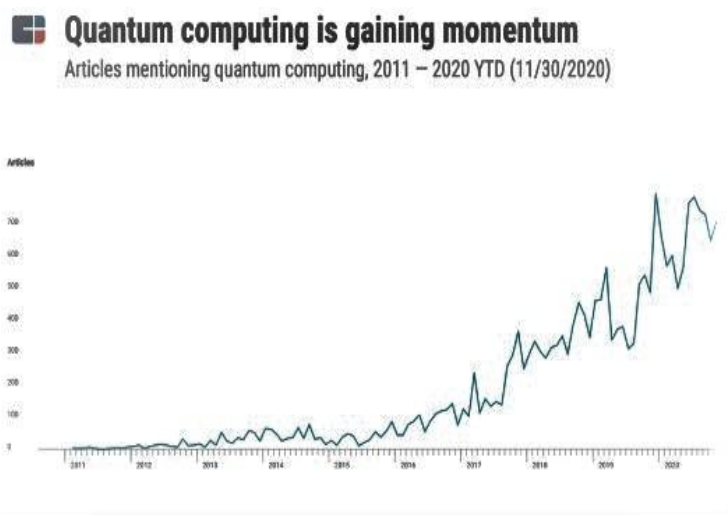

Fig. 16. Graph representing Growth in Quantum Computing Sector

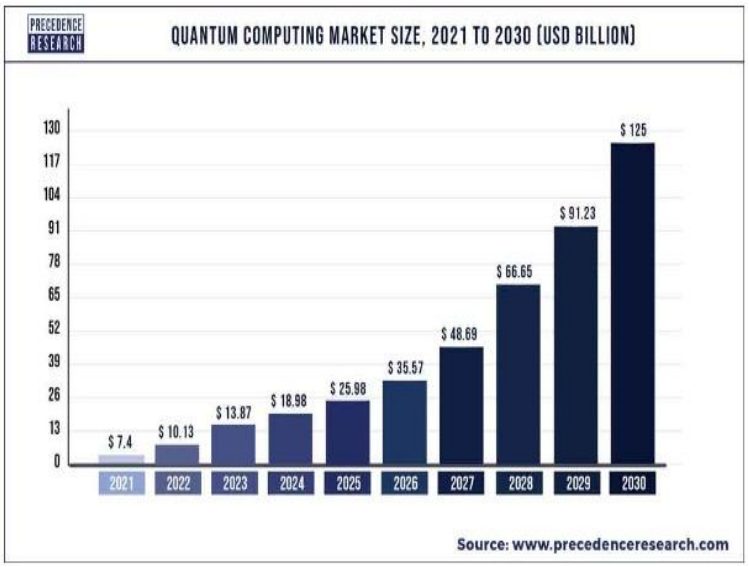

Fig. 17. Graph representing Market Size of Quantum Computing Sector

B. Latest Happenings and The Future Of Quantum Computing

Commercialization Of Quantum Computing: Quantum computing is expected to become more commercially viable in the near future , with real customers , real revenue and real products.

Increasing Qubit Count and Coherence times: The number of qubits in a quantum computer is expected to increase, along with coherence times.

Development of New quantum Algorithms: As the capabilities of quantum computers increase, new quantum algorithms and optimization techniques are being developed.

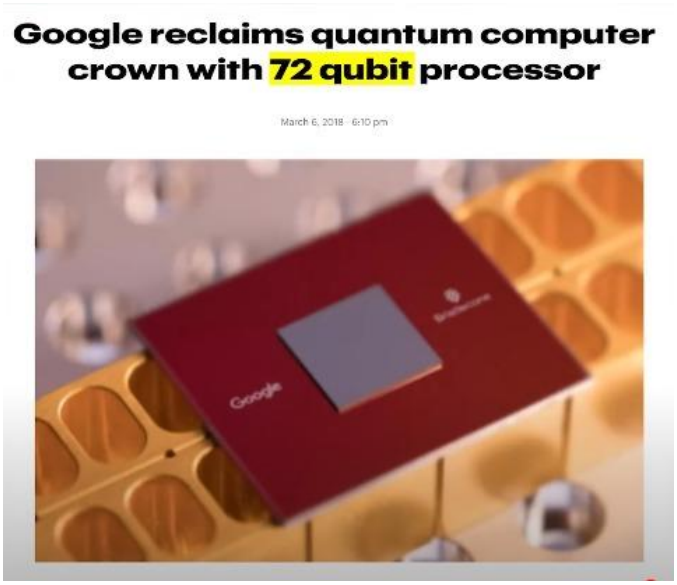

Fig. 18. Google reclaiming Quantum computer crown

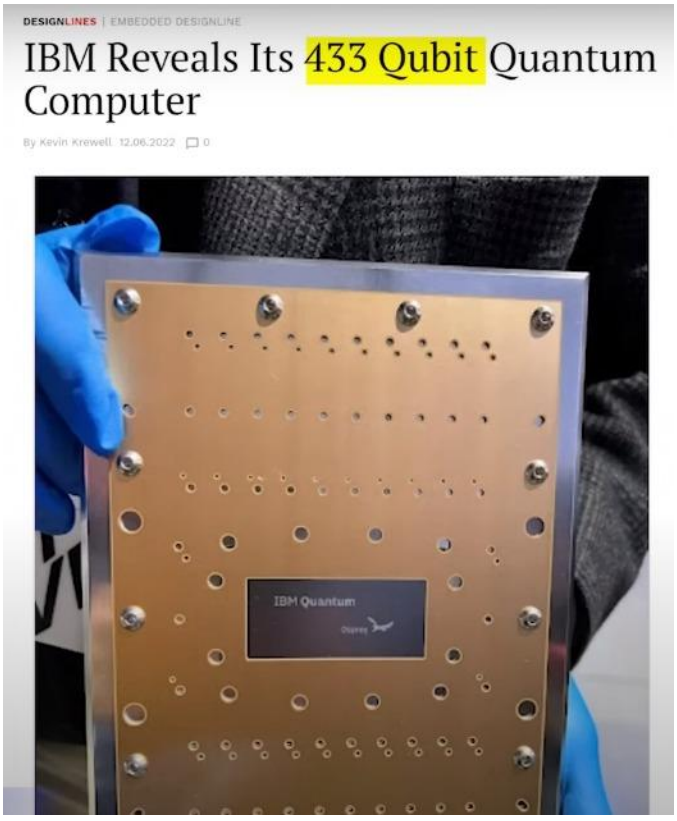

Fig. 19. IBM Reveals its 433 Qubits quantum computer

IV. Conclusion

In this paper we discussed How a Quantum Computers works wherein we discussed all the processes and latest Quantum computers including Superposition of Qubits, Exponential growth, Google's SYCAMORE computer, Quantum Entanglement, Quantum interference, Quantum Decoherence, Electromagnetic Pulses and at the end we discussed about the latest Research trends.

V. Result

Quantum computing is poised to reshape the landscape of computation, offering the potential for solving complex problems that were previously infeasible for classical computers. Its growth and development continue to be closely watched by both the scientific and business communities.

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