Quantum Computing with Oscillatory Quanta

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ABSTRACT

The linear superposition principle and the quantum entanglement phenomenon play crucial roles in the fields of quantum computing and information. Their current interpretations are not satisfactory for the need of quantum computing and information. To reduce the measurement-bias of the current interpretation of the quantum linear superposition principle, this paper presents an alternative interpretation: A physical quantity of a quantum object keeps oscillating between the allowed values of the physical quantity. Thus, a quantum system is inherently deterministic, but it appears to be probabilistic because of randomness in timings of measurements. Then, to show that the so-called quantum entangled objects need not interact or communicate with each other, the paper presents an alternative interpretation of the quantum entanglement phenomenon: Quantum objects appear to be entangled if and when each physical quantity of these objects undergoes synchronous oscillations. An experimental method is presented to validate this interpretation. Quantum entanglement due to synchronous oscillations can lead to more and better ways of quantum computers. The paper introduces Excel and Python quos package approaches to simplify and expedite designing and simulating quantum computing circuits.

Keywords: Quantum Mechanics; Linear Superposition; Quantum Entanglement; Quantum Computing; Synchronous Oscillations; Python Package

1. INTRODUCTION

At the heart of the rapidly advancing fields of quantum computing and quantum information[1,2] is the phenomenon of so-called quantum entanglement.[3–6] Quantum entanglement is[1] "a fundamental resource of Nature, of comparable importance to energy, information, entropy, or any other". Therefore, a sound understanding of this phenomenon is of paramount importance for the progress of these fields. At the heart of the phenomenon of quantum entanglement is the principle of so-called linear superposition.[7,8] Therefore, a sound understanding of this principle is of paramount importance for understanding the phenomenon of quantum entanglement.

The linear superposition principle is a foundational principle of quantum mechanics.[7,8] The current probabilistic interpretation[9–11] of this principle and of quantum mechanics gives too much weight to measurements. This interpretation indirectly implies that a quantum system's actual state is irrelevant without measurements; it is like saying that there is no sound unless it is heard. This interpretation cannot satisfactorily explain the quantum entanglement phenomenon.[3–6] Some physicists[12] had attempted to explain quantum mechanics in terms of hidden variables or pilot waves. However, such explanations were too laden with words and were proved to be invalid. To avoid these shortcomings, this paper presents an alternative interpretation: A physical quantity of a quantum object keeps oscillating between the allowed values of the physical quantity. For example, an electron has pendulum-type spin (oscillating between two values) instead of a gyroscopic spin (having a fixed value). Thus, a quantum system may be inherently deterministic, but it seems to be probabilistic only because of randomness in timings of measurements.

There have been tremendous efforts in recent years to better understand and nail down the phenomenon of quantum entanglement. However, our understanding so far is far from satisfactory. The current interpretation implicitly assumes that two so-called quantum-entangled objects have to interact with each other for their measured values to synchronize. It indirectly implies a spooky action at a distance, and leads to the EPR paradox.[13] It cannot explain quantum entanglement observed in many biological[14–18] and abnormal settings. To resolve these issues, this paper presents a different interpretation for the quantum entanglement phenomenon: Quantum objects appear to be entangled if and when a physical quantity of these objects undergoes synchronous

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oscillations. The paper proposes an experiment similar to experiments[19,20] carried out so far to validate this interpretation.

The interpretations proposed here have far-reaching implications and many practical applications. Quantum entanglement based on synchronous oscillations implies more and better possibilities of quantum computing. It can lead to new types of quantum computers,[21–26] which can be more powerful and reliable than emulated quantum computers proposed earlier.

Existing software platforms and packages[27–30] for designing and simulating quantum computing circuits are not suitable for large-scale circuits, since they require the user to add a code line for each gate. The paper introduces an Excel macro file named quos.xlsm and a Python package named quos,[31,32] which can greatly improve the ease, speed, compactness, and portability of designs and simulations of quantum computing circuits.

2. LINEAR SUPERPOSITION

2.1 States and Measurements

States and measurements of a system,[7,8] whether classical or quantum, can be classified in various ways.

States can be spatial or temporal, structural or behavioral, reversible or one-way or irreversible, discrete or continuous, and periodic or aperiodic. Spatial states are generally structural and describe a particle, whereas temporal states are generally behavioral and describe a wave.

A cat's front and back states[33] are spatial, structural, irreversible, discrete, and aperiodic. A cat's awake and sleeping states are temporal, behavioral, reversible, discrete, and maybe periodic. A cat's living and dead states are temporal, behavioral, one-way, discrete, and aperiodic.

States can have parent-child relationship. A cat's awake and asleep states are children states of the cat's living state.

Measurements can be terminal or intermittent, primary or secondary, destructive or nondestructive, discrete or continuous, and periodic or aperiodic.

Finding a particle's final position is a terminal measurement, but finding a particle's trajectory is an intermittent measurement. Seeing whether Schrodinger's cat[33] is alive by opening the cage is a primary measurement, but inferring whether the cat is alive by listening to sounds from the cage's walls is a secondary measurement. Checking the pattern generated by an electron beam on the screen in a two-slit experiment is destructive with respect to the electron, but tracking the movement of an electron can be nondestructive. Counting the number of stars every day at 11 pm is a discrete and periodic measurement, but continuously logging the ocean waves while occasionally visiting a beach is a continuous and aperiodic measurement.

In quantum mechanics, the term 'measurement' generally refers to a terminal measurement, and an intermittent measurement may be referred to by the term 'observation'.

2.2 Volume and Net

Figure 1 is a schematic illustration of locations of states and measurement devices. States are located on a net in a classical environment, on a surface in a classical-quantum environment, and in a volume in a quantum environment. Measurement devices are located on a net in all these environments.

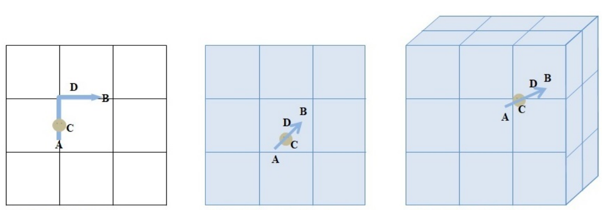

Figure 1. Schematic illustration of locations of states and measurement devices

In a classical net environment, a state is either 0 or 1 bit. In a classical-quantum plane environment, a state is a linear combination of 0 and 1 bits with real-valued coefficients; classical-quantum measurements can be interpreted as projections of plane-based locations to the net. In a quantum volume environment, a state is a linear superposition of 0 and 1 bits with complex-valued coefficients; quantum measurements can be interpreted as projections of volume-based locations to the plane of the net and then projections of the projected locations to the net. Interpreting measurements in terms of projections can be helpful in understanding quantum mechanics and developing quantum computing.

In a classical net environment, the length of path D of walk of an ant C from point A to point B is 2 units. In a classical-quantum plane environment, or in a quantum volume environment, the length of path D of walk of an ant C from point A to point B is $\sqrt{2}$ units. Thus, a quantum volume environment can reduce the distance of evolution of a system between two points. This can qualitatively explain why Grover's quantum search algorithm reduces search steps from N to square root of N.

2.3 Current Interpretation

A quantum system ψ is generally expressed as a linear superposition[7,8] of its basis states.

$$\psi = \sum_{i=1}^{n} C_i \left| i \right\rangle \tag{1}$$

According to the currently-held probabilistic interpretation of quantum mechanics, a measurement of a quantum system reveals a random basis state $|j\rangle$ with a probability $\overline{C_j} C_j$.

This interpretation has several shortcomings.

- It focuses only on terminal measurements, and ignores possibilities of intermittent, secondary, and nondestructive measurements.
- It implicitly assumes that a system has no meaning until a (terminal) measurement is made on it.
- It fails to explain why a (terminal) measurement reveals only a certain basis state.
- It fails to explain the quantum entanglement phenomenon.

2.4 Proposed Interpretation

The following oscillations-based interpretation extends the wave-particle duality principle. It can remove undue importance of measurements while describing a quantum system, and can explain why a measurement would reveal a certain basis state.

- A quantum system can have a multitude of possible states.
- In certain types of states, such as a cat's awake and sleeping states, the possible states are orthogonal to one another, and cannot be reduced to a less number of states. The possible states act as the basis states of the system.
- In certain types of states, such as a circularly polarized light's states, the possible states are not necessarily orthogonal to one another, and can be reduced to a less number of states, which act as the basis states of the system. The basis states may be chosen arbitrarily. While conventionally a set of orthogonal basis states is chosen, it is possible to choose a set of non-orthogonal basis states, such as coherent states of quantum optics.
- If states are reversible, a quantum system oscillates among its possible states one after the next one.
- In equation 1, $\overline{C_j} C_j$, the product of the Hermitian conjugate of the j-th coefficient with the j-th coefficient, denotes the fraction of the time the j-th basis state predominates.

- In equation 1, C_j, the j-th coefficient has value of 1 for times t between $t_{k,j-1}$ and $t_{k,j}$, and has values of 0 for other times. The subscript k here denotes the cycle number of oscillations.
- In most cases, the cycle time of oscillations is so small that a measurement sees a random basis state depending on when the measurement is taken.
- The system's oscillations can be periodic, semi-periodic with some pattern, or aperiodic.
- The system's oscillations are periodic in the beginning, but the system's passage through the environment can make the oscillations erratic.
- A quantum system appears to be random or probabilistic only because of randomness or probabilistic nature in timings of measurements.

Figure 2 is a schematic of oscillations of a quantum system among its up and down spin states.

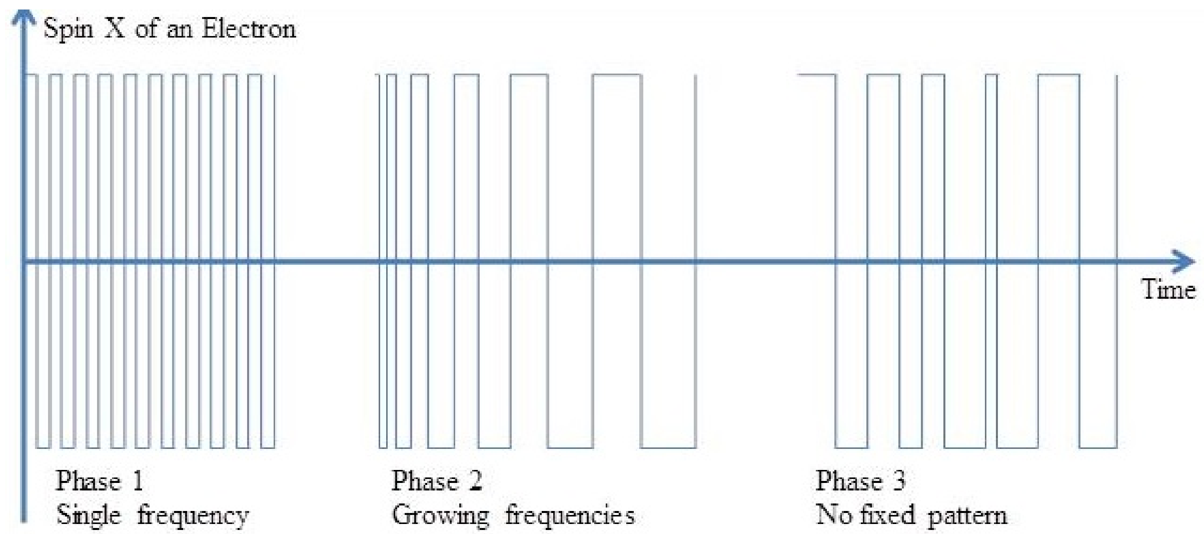

Figure 2. Oscillations of a quantum system among its up and down spin states

2.5 Oscillatory Spin

To illustrate this alternative interpretation, consider the spin of an object. If the spin has a fixed-directional value, the spin represents a uni-directional gyroscopic spin. On the other hand, if the spin oscillates between its up and down values, the spin represents a bi-directional pendulum-type spin.[34] Figure 3 contrasts these two types of spins.

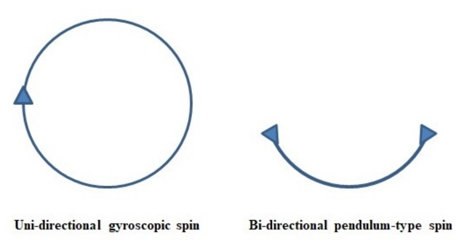

Figure 3. Uni-directional gyroscopic spin versus bi-directional pendulum-type spin

A particle known to have a spin of ½ or 1 or 2 rotates ½ circle or 1 circle or 2 circles in one direction before reversing its direction of rotation.

2.6 Spherically Polarized Waves

The amplitude of a linearly polarized wave oscillates in a fixed plane. The amplitude of a circularly polarized wave oscillates in a plane rotating around the axis of travel. The amplitude of a spherically polarized wave oscillates in a plane rotating around the point of travel.

If an electron's wave is spherically polarized wave, in a two-slit experiment, it will produce 3-dimensional holographic interference fringes in a holographic screen behind the two slits.

A possible reason for why the coefficients of the terms in a linear superposition equation are complex-valued rather than real-valued is that a three-dimensional (spherical) polarization is cast as a two-dimensional (circular) polarization. Imaginary values of the terms represent possible fast oscillations along the time axis or the axis of travel.

3. QUANTUM ENTANGLEMENT

3.1 Schrodinger's Interpretation

The term 'quantum entanglement' was coined by Schrodinger[33] to describe a quantum phenomenon in which two quantum objects produce same measurement values for a certain physical quantity. According to Schrodinger, and according to many people today, when two quantum objects are in a so-called quantum-entangled state,[3–6] they somehow interact with each other for their measured values to synchronize. Such an interpretation indirectly implies a spooky action at a distance, and leads to the EPR paradox.[13]

3.2 Bell's Interpretation

According to Bell,[35,36] a quantum system of two quantum-entangled objects can be represented as

$$(|0\rangle_A \otimes |0\rangle_B + |1\rangle_A \otimes |1\rangle_B) \quad or \quad (|0\rangle_A \otimes |1\rangle_B + |1\rangle_A \otimes |0\rangle_B) \tag{2}$$

In general, a quantum system of two objects can be represented as

$$C_{00}(|0\rangle_A \otimes |0\rangle_B) + C_{11}(|1\rangle_A \otimes |1\rangle_B) + C_{01}(|0\rangle_A \otimes |1\rangle_B) + C_{10}(|1\rangle_A \otimes |0\rangle_B) \tag{3}$$

The quantum entanglement index of a system is given by

$$abs(C_{00} + C_{11} - C_{01} - C_{10})/abs(C_{00} + C_{11} + C_{01} + C_{10}) \tag{4}$$

Thus, Bell interpreted and quantified the quantum entanglement phenomenon in terms of correlations.

However, Bell's interpretation is silent about the physical basis of quantum entanglement between two far-away quantum objects.

3.3 Proposed Interpretation

The following interpretation of the quantum entanglement phenomenon stems from the forementioned proposed interpretation of the linear superposition principle. It does not require quantum-entangled particles to interact with each other, and can thus resolve issues related to communication speeds.

- When two particles are ejected from a common source, their physical quantities oscillate, synchronously with respect to each other, thereby making them appear as 'entangled'.

$$S_1(t) = S_{10}.sin(\omega t)/|sin(\omega t)| \tag{5}$$

$$S_2(t) = S_{20}.sin(\omega t)/|sin(\omega t) \tag{6}$$

- Different environments surrounding the two particles disturb oscillations of the particles and make the oscillations asynchronous, thereby removing their entanglement.

- For quantum entanglement to be present, oscillations of physical quantities of quantum-entangled objects need not be with a single frequency; they may obey some other pattern.

Figure 4, illustrates synchronous oscillations of spin x of two quantum-entangled electrons.

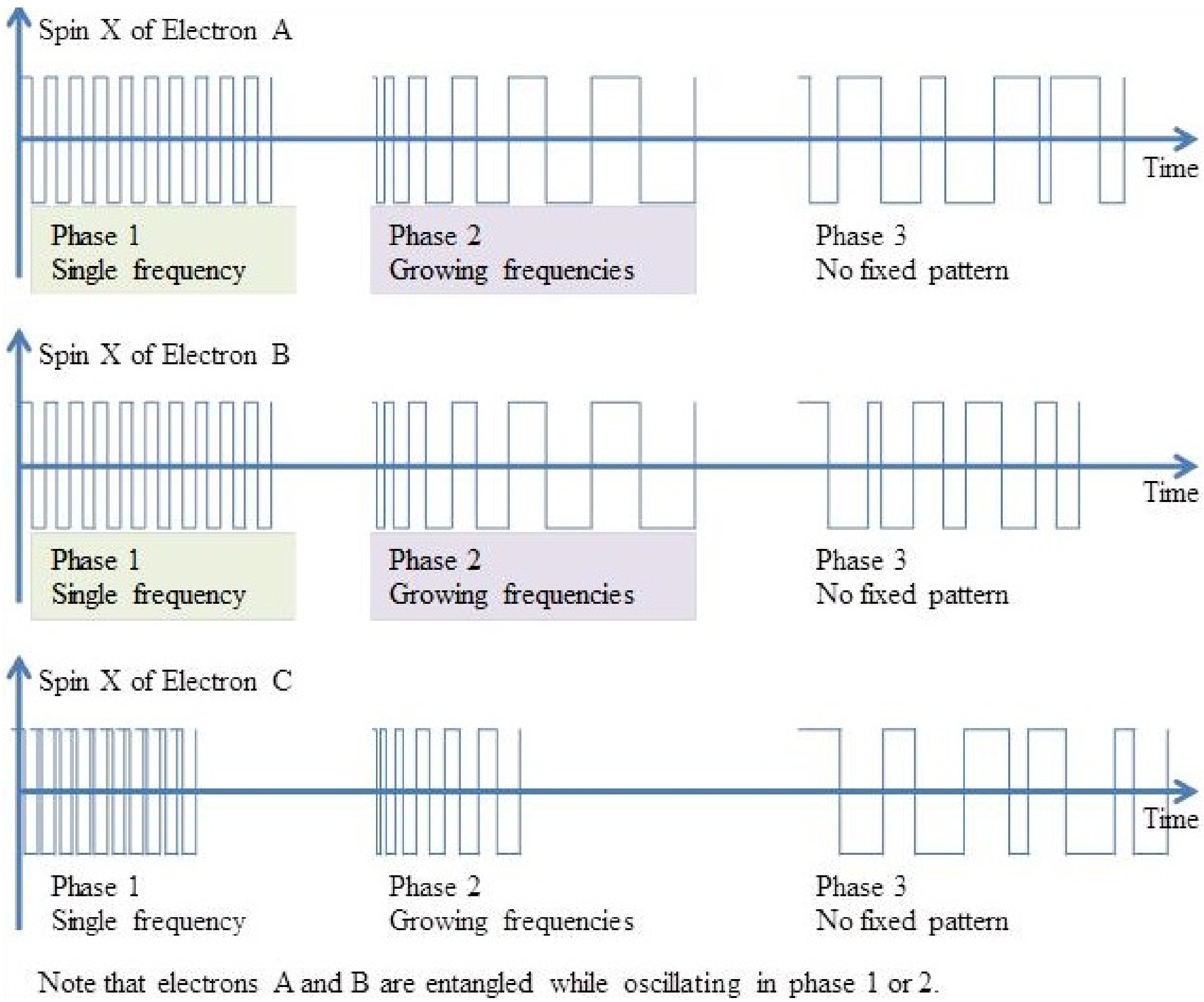

Figure 4. Synchronous oscillations of spin x of two quantum-entangled electrons

3.4 Implications

Quantum entanglement based on synchronous oscillations does not involve any communication[37–39] or transportation[40,41] in a traditional way.

Quantum phenomena observed in many biological systems[14–18] can be explained in terms of quantum entanglement due to synchronous oscillations.

3.5 Experimental Validation

It is possible to determine whether two electrons are entangled and whether their entanglement is due to synchronous oscillations. Figure 5 shows a schematic of such an experiment.[19,20]

An atom emits two electrons: electron A and electron B. A light transceiver sends two similarly polarized lights simultaneously to the two electrons. The electrons return polarized lights to the light transceiver. The light transceiver measures polarizations of the lights returned by the electrons.

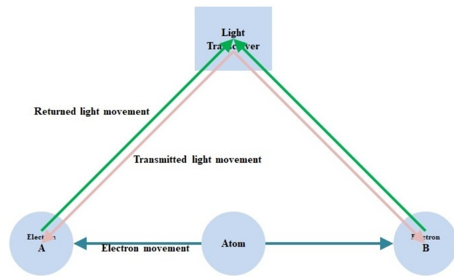

Figure 5. Experimental set-up to study quantum entanglement

Polarizations $[a_x(t),\ a_y(t),\ a_z(t)]$ of the light returned by the electron A at time t, and polarizations $[b_x(t),\ b_y(t),\ b_z(t)]$ of the light returned by the electron B at time t are measured.

For each measurement set, a CHSH quantity[42–45]

$$((a_x(t) + a_y(t))b_x(t) + (a_x(t) - a_y(t))b_y(t)) \tag{7}$$

is computed; its individual values should be 2 or -2. Values computed for the CHSH quantity for different values of t are averaged. If the averaged value is other than 0, 2, or -2, it would imply that the two electrons are quantum entangled.

The ratio of the number of sets for which $[a_x(t),\ a_y(t),\ a_z(t)]$ equals $[b_x(t),\ b_y(t),\ b_z(t)]$ to the total number of sets is computed, and likewise, the ratio of the number of sets for which $[a_x(t),\ a_y(t),\ a_z(t)]$ equals $[-b_x(t),\ -b_y(t),\ -b_z(t)]$ to the total number of sets is computed. The higher of these two ratios gives the quantum entanglement index of the two electrons. Value of 0 for this index implies absence of quantum entanglement, value of 1 for this index implies complete quantum entanglement, and any other value implies partial quantum entanglement.

An adequately high total number of sets of measurements is necessary to make sure that correlations in polarization measurements are not mainly due to measurement errors or some factors to be ignored. More sets of measurements and more computations are needed to determine whether a quantum entanglement is due to synchronous oscillations.

Fourier analyses of polarizations $a_x(t)$, $a_y(t)$, $a_z(t)$, $b_x(t)$, $b_y(t)$, and $b_z(t)$ is carried out with respect to time t, thereby computing frequencies of polarizations. A very wide range of frequencies would imply absence of synchronous oscillations of the two electrons, and a few discrete values of frequencies would imply presence of synchronous oscillations of the two electrons.

4. QUANTUM COMPUTING

4.1 Current Status

Quantum computing[1,2] relies heavily on the linear superposition principle and the quantum entanglement phenomenon. Prior to about 2000, it was believed that quantum algorithms require systems that are truly quantum in nature. However, further research on fundamental aspects of quantum algorithms has shown[21–26] that sub-atomic-level quantum systems are not mandatory for most quantum algorithms, and that many quantum algorithms can be realized with classical systems involving harmonic oscillations. Classical systems can be suitable for visualizing some concepts of quantum algorithms and quantum computing, but they are not likely to be widespread, since they are extremely slow in operations, consume a lot of power, and are difficult to mass produce.

Like the classical systems suggested for emulating quantum computing, photonics based quantum computing systems[46–49] rely on harmonic oscillations. Unlike the classical systems, photonics based systems are extremely fast in operations, consume less power, and can be mass produced. Unlike the superconductor or trapped-ion based systems, photonics based systems can be operated at room temperatures and for longer distances and times. As a result, photonics based systems are likely to predominate in the quantum computing field.

A few research teams[50] have studied the feasibility of phonons (acoustic waves) as a possible mechanism for quantum computing. Such systems do not require sophisticated cooling and vacuum equipment, and are easy for tracking and controlling qubits and feeding and fetching data.

NASA and other agencies have recently studied possibilities of exploiting the quantum nature of electromagnetic radiations inside or towards the International Space Station.[51,52]

4.2 Proposed Systems

The schemes as narrated above for classifying states and measurements can offer a method for categorizing different schemes of quantum computing. Such a categorization can be quite useful for understanding scopes and limitations of different schemes.

The interpretations as proposed above for the linear superposition principle and the quantum entanglement phenomenon have many practical implications for the field of quantum information. A quantum system with oscillations among allowed states can offer an enormous number of ways for storing information[1,2] in terms patterns of oscillations. Just as the field of telecommunication[37–39] has used oscillations for storing and conveying information, the field of quantum information can benefit from oscillatory quanta.[53]

The proposed interpretations can have many practical implications for the field of quantum computing. These interpretations imply that it will be possible to achieve linear superposition and quantum entanglement more easily and in more systems than believed earlier. This implies that it should be possible to devise various types of wave based systems for quantum computing. Many new hardware or software based quantum computers can be designed, in which objects are artificially entangled by synchronous oscillations.

Due to their short wavelengths, visible electromagnetic radiations are difficult to separate and track at the photon level. However, due to their longer wavelengths, microwaves and radio waves are easier to separate and track at the photon level. Hence, it will be possible to devise a quantum computer that uses microwaves or radio waves.

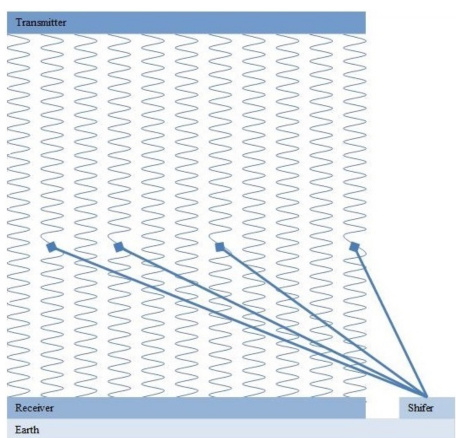

Figure 6. Scheme for a microwaves based quantum computer

Figure 6 illustrates a scheme proposed for a quantum computer. Here, microwaves travel from a transmitter to a receiver. Depending on the requirement of gates, a phase shifter shifts phases of certain wavelets. The phase shifter can be like an electron gun in a CRT monitor.

5. QUOS PACKAGE

There exist numerous software platforms and packages[27–30] for designing and simulating quantum computing circuits. Most of them require the user to add a code line for each gate. This makes these platforms and packages not suitable for large-scale circuits.

To improve the ease, speed, compactness, and portability of designs and simulations of quantum computing circuits, an Excel macro file named quos.xlsm and a Python package named quos were developed. They have been made publicly available[31,32] through GitHub at Quos repository on GitHub and through PyPi at Quos package at PyPi.

For designing a circuit using Excel, appropriate codes of quantum gates are written in top-left cells in a spreadsheet in a copy of the quos.xlsm file. When the qa macro is clicked from the Excel menu bar, the macro generates a spreadsheet that contains gate plots, Bloch sphere plots or probability bar charts, qubit state angles or probabilities, and qubit state numbers.

For designing a circuit using Python, quos package is imported, a string such as

$$\begin{aligned}txt = {}&"1,3,0|Q3060,5,0|H,a,1|Y,1,2|Z,2,2|X,3,2|Y,4,2|Z,5,2|X,6,2|S,2,3|\\&T,4,3|V,6,3|Rx30,1,4|Ry15,2,4|Rz15,3,4|Rz30,4,4|Ry15,5,4|Rx15,6,4|\\&Ph15,2,5|Pp30,4,5|C,2,6,C,5,6,X,3,6|Cd,1,7,Ph15,2,7|U303015,4,7|\\&U151530,6,7|C,1,8,X,2,8|Sw,4,8,Sw,6,8|iSw,3,9,iSw,4,9|M,a,10"\end{aligned} \tag{8}$$

is written to specify the circuit configuration, the command

$$quos.qg(txt) \tag{9}$$

is written to plot quantum gates, and the command

$$quos.qb(txt) \tag{10}$$

is written to simulate the circuit and plot Bloch spheres or probability charts.

Figure 7 shows inputs and outputs of an exemplary circuit in Excel and Python.

On an adequately capable computer, the quos.xlsm based approach can handle up to about one million qubits and up to about ten thousand operations on each qubit, and the quos package based approach can handle unlimited number of qubits and unlimited number of operations on each qubit. The database nature of the quos.xlsm approach and Pandas data-frames returned from the quos package approach make it possible to connect these approaches to appropriate databases, so that the design and simulation become robust, unlimited, and interactive.

Future versions of quos.xlsm and quos package will allow users to upload circuit designs to, and download measurement results from, some of the available quantum computers.

6. CONCLUSIONS

The periodic oscillations interpretation of quantum linear superposition can reduce the measurement-bias of the current interpretation. The synchronous oscillations interpretation of the quantum entanglement phenomenon can explain the root cause of this phenomenon without leading to issues like the EPR paradox. Quantum entanglement due to synchronous oscillations can lead to more and better ways of quantum computers. The quos.xlsm and quos package can improve the ease, speed, compactness, and portability of designs and simulations of quantum computing circuits.

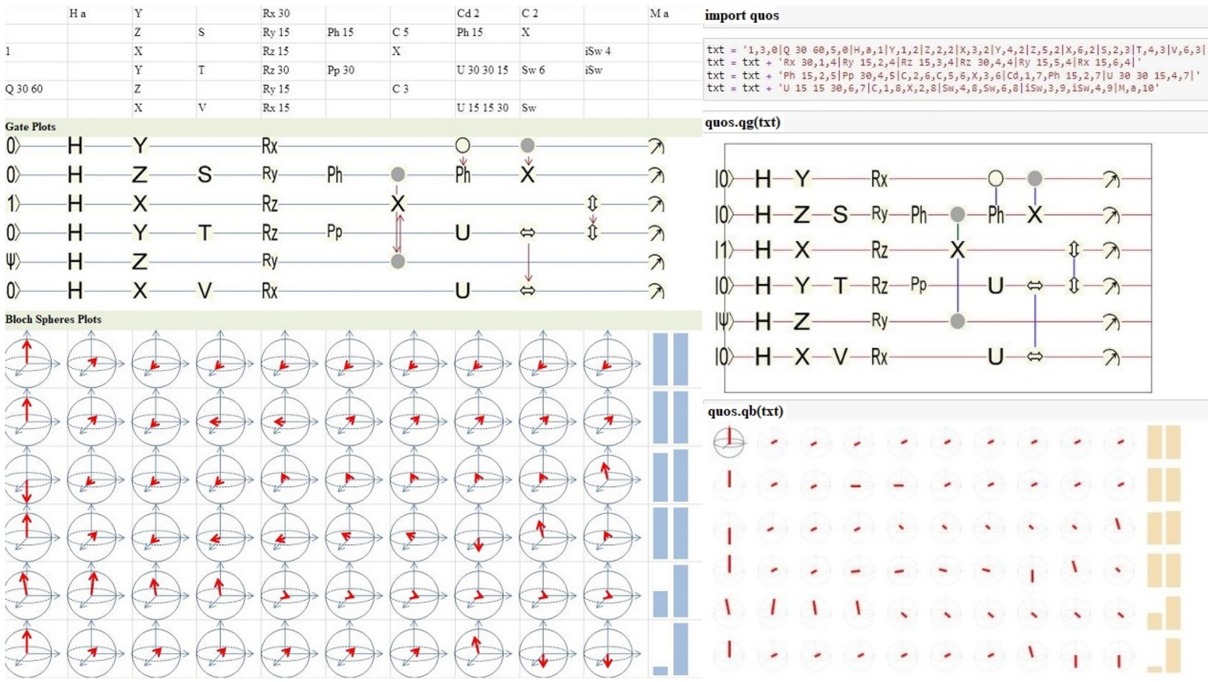

Figure 7. Inputs and outputs of an exemplary circuit in Excel and Python

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