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SLW QUANTUM COMPUTING WEBINAR MINISERIES

A Practical Guide to Quantum Technology for Patent Practitioners

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Panel



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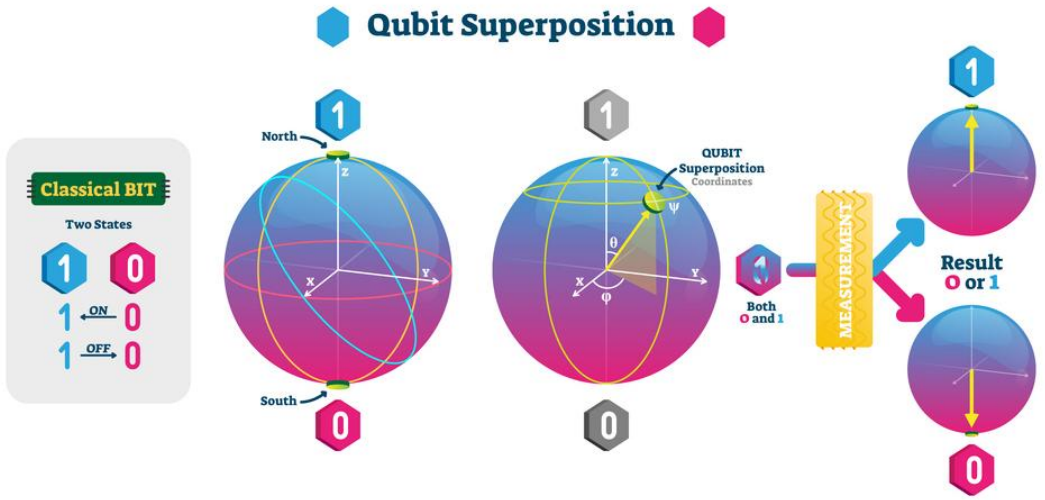
Moderator

Outline

- Quantum Mechanics - Concepts
  - Superposition
  - Interference
  - Decoherence
  - Entanglement
- Communication
  - Establishing secure networks leveraging quantum properties
- Sensing and Metrology
  - Using fragile quantum states for ultra-precise measurements
- Computing
  - Solving computational problems through manipulating complex multi-qubit probability spaces

Superposition

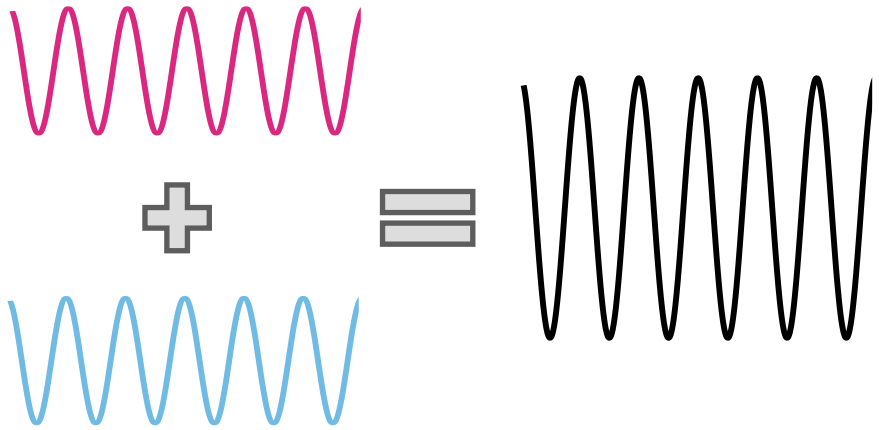
- A quantum entity can exist in a linear combination of states $|0\rangle$ and $|1\rangle$
- $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$
- α and β can be real-valued positive or negative, or complex-valued, ‘probability amplitudes’.
- $|\alpha|^2$ and $|\beta|^2$ are the probabilities to find the system $|\psi\rangle$ in the corresponding $|0\rangle$ state or $|1\rangle$ state upon measurement.

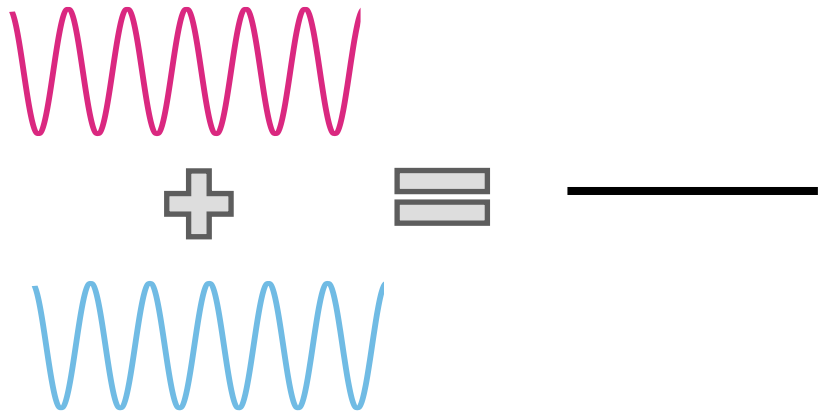


Interference

- Two coherent waves (wavefunctions) can combine by addition
- Constructive interference
- Destructive interference
- Superposition (in a classical sense) of two or more waves at a given point

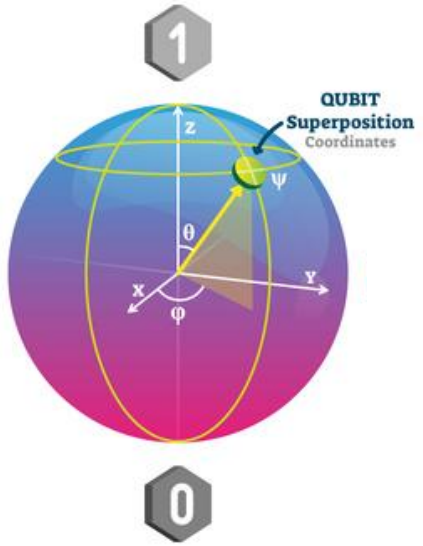
- Systems having coherent quantum superposition can exhibit interference with each other.





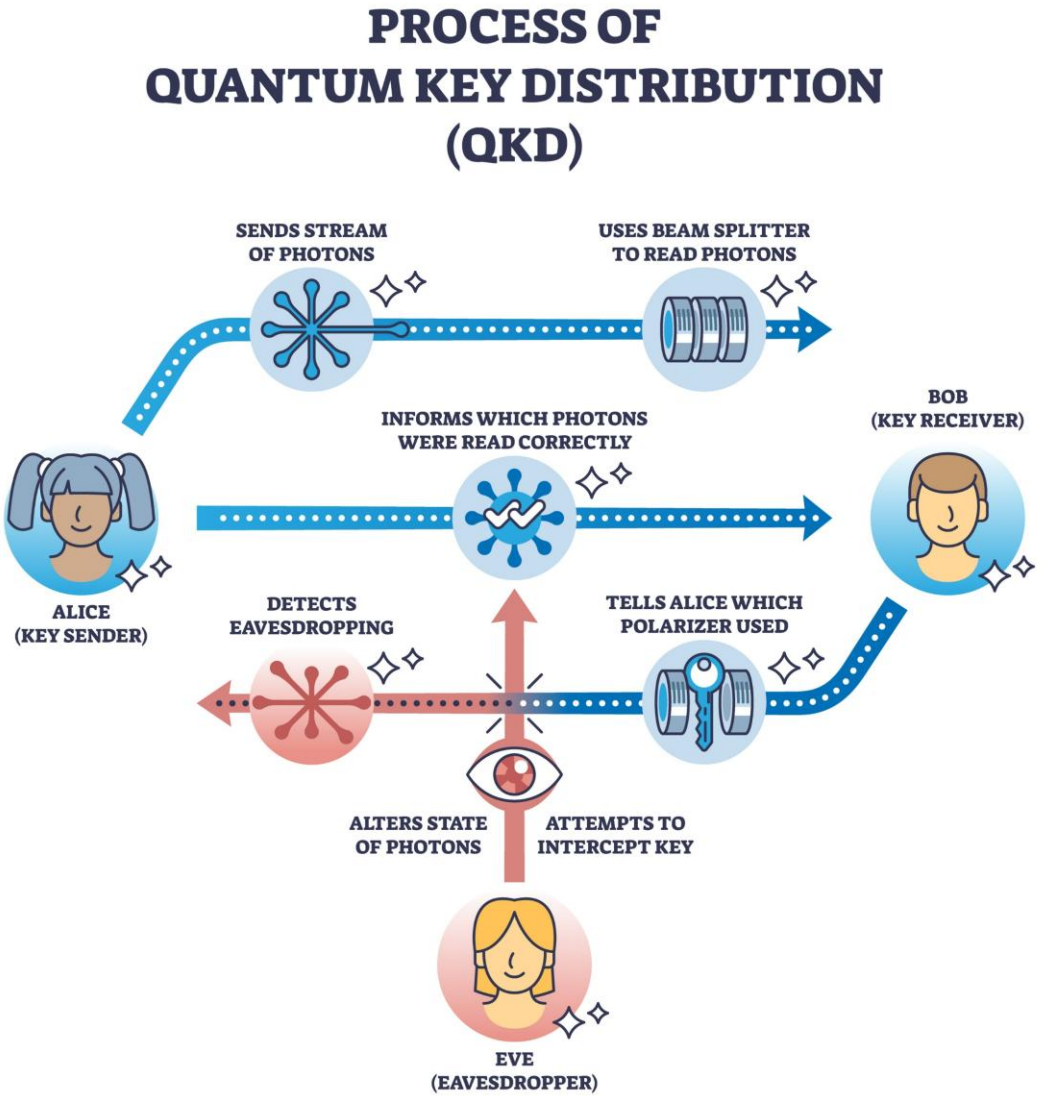
Decoherence

- Loss of quantum coherence
- System behaves as a classical statistical ensemble rather than a coherent quantum superposition
- Qubit – has a ‘coherence lifetime’ during which quantum operations must be carried out to realize quantum parallelism



Entanglement

- The quantum state of each particle in a group cannot be described independently of the state of the others, even when the particles are separated by a large distance.
- Mathematically, can not separate the basis states.
- $|00\rangle, |01\rangle, |10\rangle, |11\rangle$
  - Superpositions of the entangled basis states
  - Bell State, equal amplitude for both in “0” and both in “1”
  - $(|00\rangle + |11\rangle)/\sqrt{2}$



Quantum Communication and QKD

- QKD
  - Leverages the observer effect. Any attempt by an adversary to eavesdrop on the quantum channel irreversibly alters the photon states, alerting users to the intrusion.
- The attenuation Barrier.
  - Photon losses in standard optical fiber add up over long distances. Quantum states can not be simply copied and amplified.
- IP Hotspot
  - Quantum Repeaters and Quantum Memory
  - ‘Entanglement Swapping’ to chain entanglement across nodes.

Sensing and Metrology

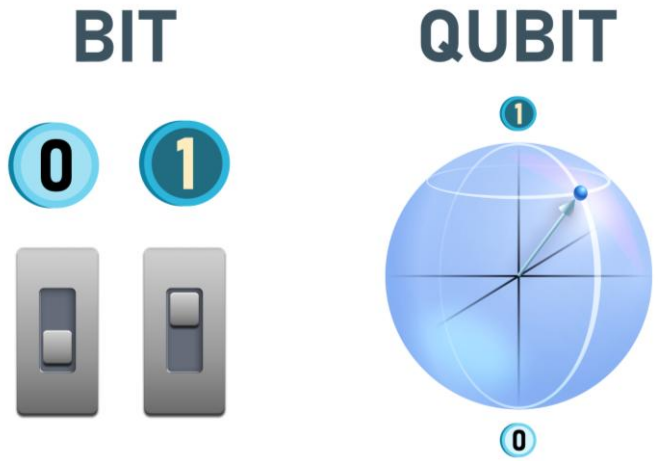
- Sensitivity of quantum states to environmental noise can be harnessed to detect minute changes in electric fields, magnetic fields, gravity, temperature, etc.
- Each sensor can be unique to the sensing application
- Quantum sensing hardware can have several (classical) engineering challenges to overcome
  - Classical hardware for control, readout, data processing

- Miniaturization of sensor form factors and dynamic range optimization – IP Hotspot

Quantum Computing

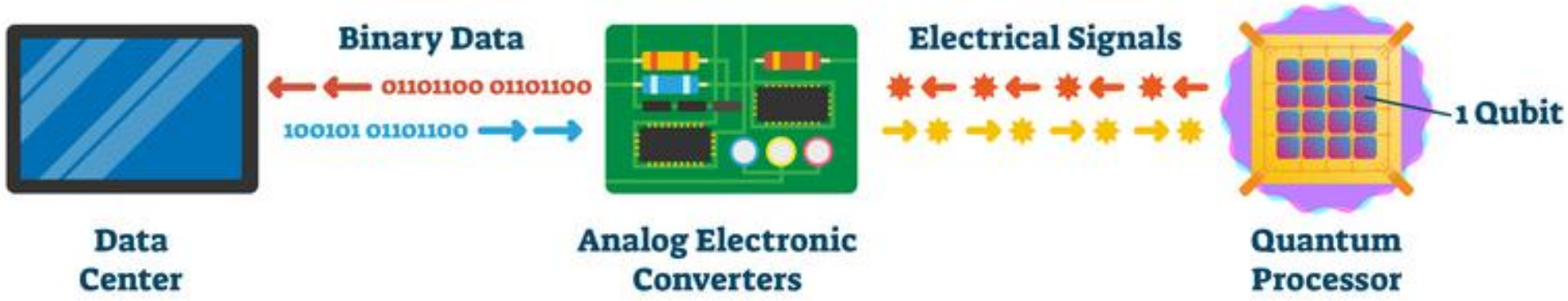
Quantum Computing

- The fundamental unit: Bits vs. qubits
- Classical bits are constrained to discrete binary states (0 or 1).
  - Computational power scales linearly with each added physical transistor
- Quantum bits (qubits) can exist as a linear combination (superposition) of ‘basis states’
  - A system of ‘n’ qubits represents 2^n possible outcomes simultaneously



Quantum Computer Blueprint

- A quantum computer is not a single, monolithic invention.
- It is a highly engineered technology stack of distinct, interdependent technologies.
- To draft and prosecute effectively, identify which layer the invention occupies. Innovations in some layers are purely hardware, and innovations in other layers are computer-implemented inventions.





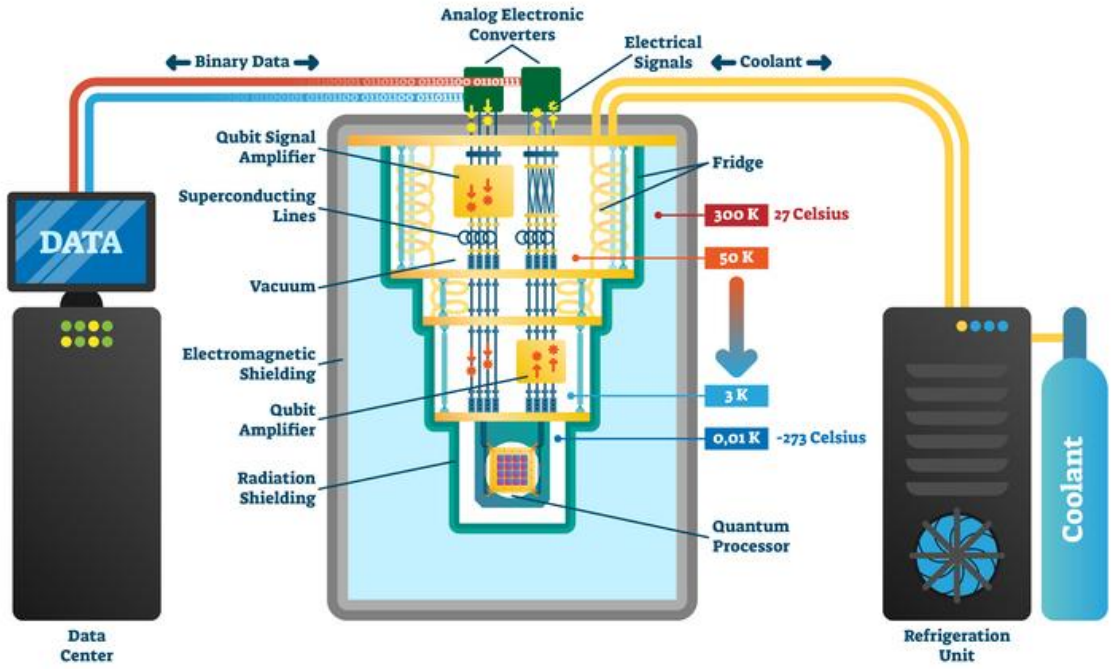
The Quantum Computing Stack

- **Layer 4: Software and Application**
  - Quantum Algorithms and hybrid classical-quantum software
  - IP Focus: Use-case specific optimizations
- **Layer 3: Error correction**
  - Algorithms mapping noisy physical qubits to stable logical qubits
  - IP Focus: Syndrome measurement, fault-tolerance
- **Layer 2: Control Systems and Enabling Hardware**
  - Microwave pulses, laser calibration, readout mechanisms
  - IP Focus: pulse scheduling, noise suppression
- **Layer 1: Quantum Register**
  - Qubits
  - IP Focus: Materials, chip/qubit system fabrication

Hardware Layer(s)

Hardware: Classical Engineering

- Cryogenics
  - Dilution refrigerators (‘cryo chandeliers’) cool systems to near absolute zero (~15 milliKelvin).
- Vacuum Systems
  - Ultra-high vacuum chambers for trapped ion and neutral ion qubits.
- Control Electronics
  - Server racks, high-stability lasers, microwave pulse generators are required to send precise control pulses to the qubit arrays (often, on a photonic chip or electrical chip).



Hardware Modalities

- **Superconducting Circuits**
  - Eg., IBM, Google
  - Fast operations, leverages existing lithography
  - Require extreme cryogenics
- **Trapped Ions**
  - E.g., Quantinuum, IonQ
  - Individual atoms trapped by electromagnetic fields
- **Neutral Atoms**
  - E.g., Quera
  - Atoms held in flexible 2D/3D grids by optical tweezers (lasers). Highly scalable topology.
- **Photonics**
  - E.g., PsiQuantum
  - Use single photons of light in waveguides
  - Operate at room temperature but have some cryogenic components (photon detectors)
- **Spin Qubits**
  - Uses the spin of electrons in silicon
  - Offers the promise of extreme miniaturization but faces immense fabrication hurdles

Superconducting Circuits

- The Mechanism: Josephson Junction
  - Creates a necessary non-linear energy level to isolate a two-level state
- Macroscopic LC circuits normally have evenly spaced energy levels.
- By inserting a Josephson Junction, a non-linear anharmonicity is introduced
- This isolates the lowest two energy states for operation as a distinct qubit using microwave pulses (e.g., 4 GHz – 8 GHz)

- IP focus: Transmon designs, microwave crosstalk mitigation, cryogenic 3D packaging

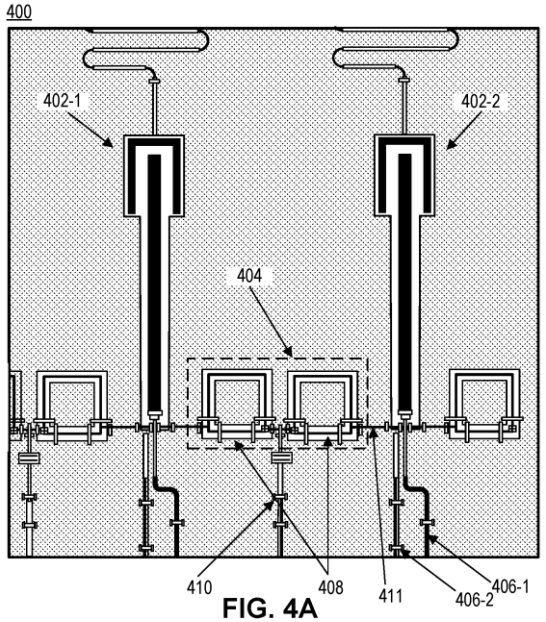


FIG. 4A

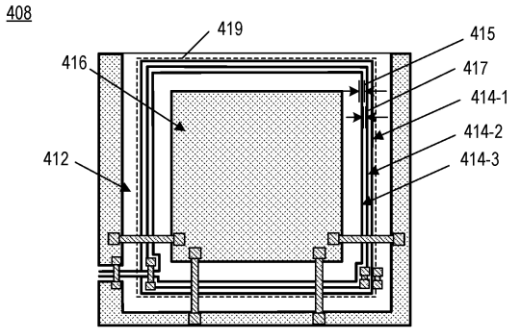


FIG. 4B

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Superconducting Circuits: Enabling Infrastructure

- **Wiring bottleneck for cryogenic and vacuum systems**
  - A dedicated physical control wire for every single qubit.
  - Routing a million cables into a dilution refrigerator is thermodynamically and physically impossible.

- **Solution**
  - Cryo-CMOS control
    - Ultra-low power classical control circuits that can operate inside the fridge at 1 to 4 Kevin without generating excessive heat that would destroy the quantum states.
  - 3D integration and TSVs
    - Stacking quantum processing units (QPUs) using superconducting TSVs to dramatically increase interconnect density and reduce latency.

Trapped Ions

- The mechanism: Individual atoms are stripped of an electron, electromagnetically suspended in a vacuum, and manipulated via lasers.
- Stable hyperfine ground states or optical levels are used as the qubit levels.
- Precision lasers or microwave signals are used to initialize the qubits, perform logic gates, and read out the final state.
- IP focus: quantum charge-coupled device (QCCD), architectures that physically shuttle ions between zones, and complex optical delivery systems.

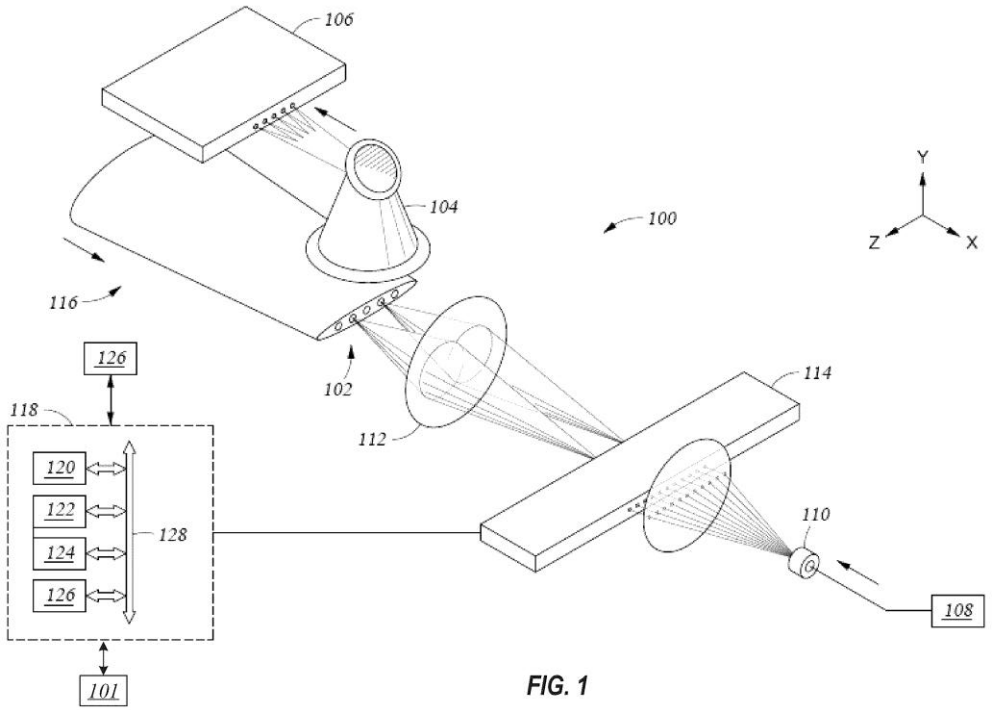


FIG. 1

US12056573B2

Neutral Atoms

- The Mechanism: Uncharged atoms held in highly dense grids by focused lasers
- Driven to high-energy Rydberg states to perform entangling logic gates
- Qubit states are atomic energy levels, stable hyperfine ground states, or nuclear spins

- Bottleneck: Laser power and alignment precision

- IP focus: Transversal gates enabled by physically shuttling blocks of atoms mid-computation, optical tweezer generation

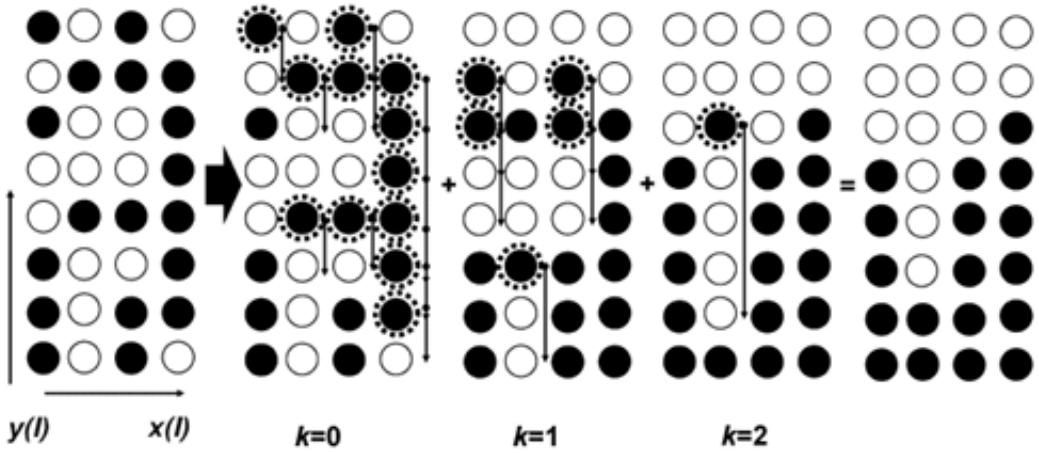


FIG. 3

US20230282385A1

Photonic Qubits

- The Mechanism: Encodes information in the polarization or the path of photons.
- Relies on measurement-based quantum computing using pre-entangled cluster states
- Bottleneck: Efficient photon generation and detection
- IP Focus: Mitigation of photon loss, deterministic single-photon sources, and optical multiplexing architectures

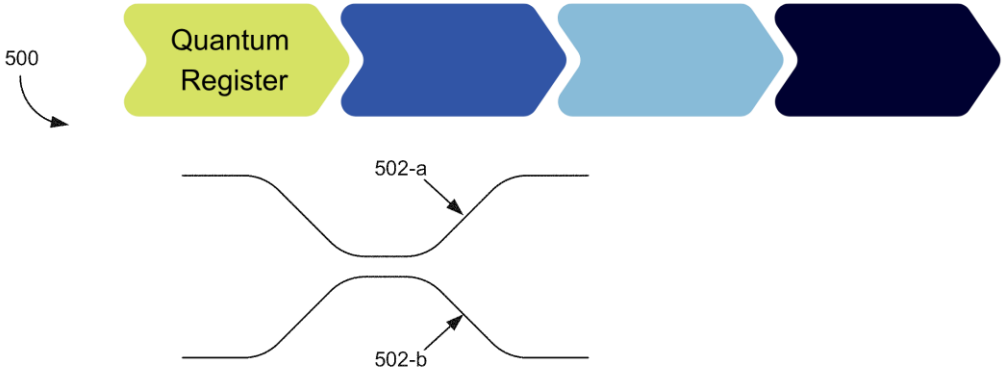


Figure 5

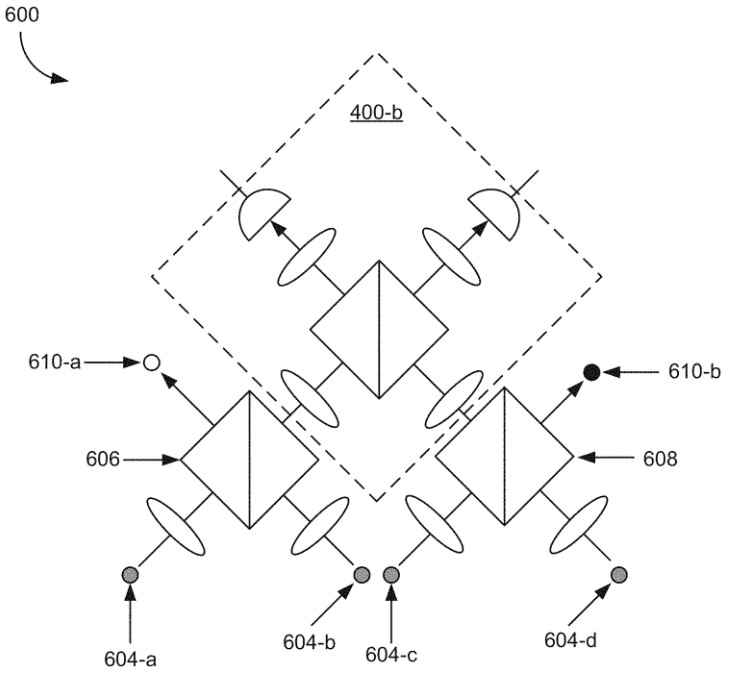


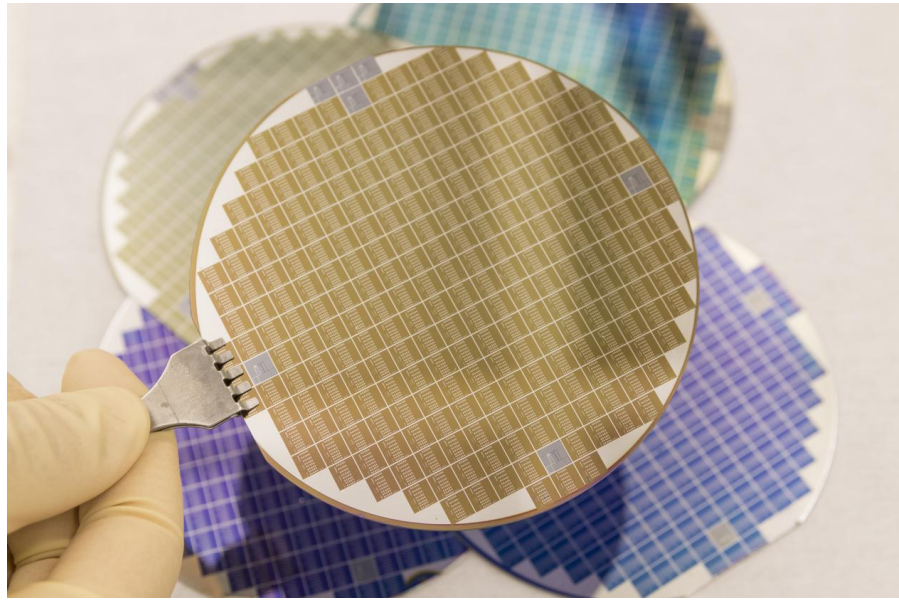
Figure 6

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Silicon Spin Qubits

- The Mechanism: Store quantum information in the spin state of a single electron confined in isotopically purified silicon-28
- Requires precise placement of dopants and specialized circuits (single-electron transistor)
- Compatible with CMOS foundries

- IP Focus: Purified silicon, cryo-CMOS electronics for control



Connective tissue

- Fault-tolerant quantum computing requires overcoming engineering challenges among classical systems within the quantum computing stack.

- Practitioners can look beyond the qubit layer. There is valuable IP in the connective tissue that make scaling possible.

Logical Layer

NISQ vs. FTQC

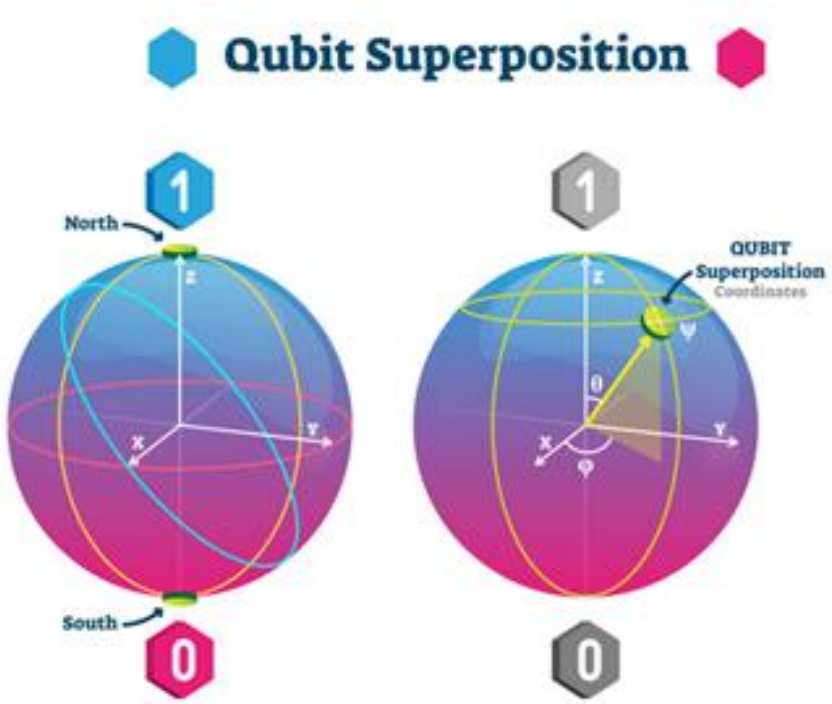
- Noisy Intermediate-scale quantum
- Current processors lack the capacity for continuous error correction. Noise overwhelms deep circuits.
- Hybrid algorithms can offload heavy lifting to classical processors

- Fault-tolerant quantum computing
- Requires a massive leap in physical qubit counts to support algorithmic redundancy

Error Correction Required

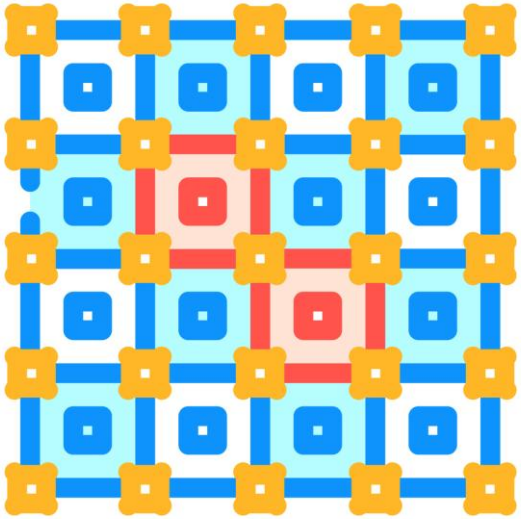
- Qubits are inherently unstable
  - Any unintended interaction with the outside world causes decoherence
- The backup dilemma
  - Information can't be copied

- Bit Flips
- Phase Flips



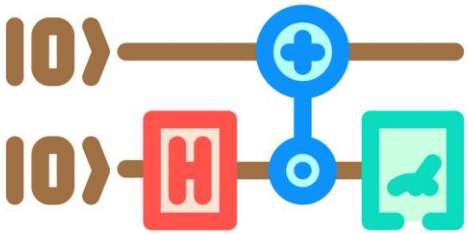
Quantum Error Correction Basics

- A logical qubit ‘spreads out’ the information across an entangled lattice of 100 to 1000 noisy ‘physical’ qubits
- Measure ‘ancilla’ qubits to detect error ‘syndromes’ in the grid, allowing the system to correct errors without ever directly looking at (and thus destroying) the actual quantum data
- It may take hundreds or thousands of physical qubits to create a single reliable logical qubit
- **Patent Strategist Takeaway:** QEC protocols, syndrome measurement techniques, and error mitigation algorithms are currently among the most heavily patented areas in quantum software



The Logical Layer: Circuits and Control

- Physical qubits follow a “prepare”, “evolve”, “measure” sequence of qubit operations.
- Qubit operations are called quantum logic gates, or “gates”.
  - Pauli-X, Pauli-Y, Pauli-Z, Hadamard (H), CNOT, Controlled Z (CZ), SWAP, Toffoli, phase
- Mental model of a single qubit gate
  - Rotation on the Bloch sphere
- A gate on a chalkboard is a precise physical action.
  - Shining a laser, firing a shaped microwave pulse at the qubit.
  - Qubits need calibration to accurately apply gates.
- Quantum Circuit
  - A choreographed sequence of gates forms a quantum circuit.



- **Patent Strategist Takeaway:** A “quantum circuit” is often articulated as a method claim describing a specific sequence of gates applied to one or more qubits.

Algorithm Showcase

Grover's Algorithm (Unstructured Search)

- Mechanism: Applies a diffusion operator to iteratively invert and amplify the amplitude of the target state ("Amplitude Amplification")
- Impact: Achieves a quadratic speedup (sqrt N) for database searching

Shor's Algorithm (Factoring)

- Mechanism: Maps the factoring problem to finding the periodicity of a function, then uses the QFT to create a massive constructive interference spike at the reciprocal of the hidden period
- Achieves exponential speedup effectively rendering current RSA public-key cryptography obsolete upon the arrival of fault-tolerant hardware

Software Stack

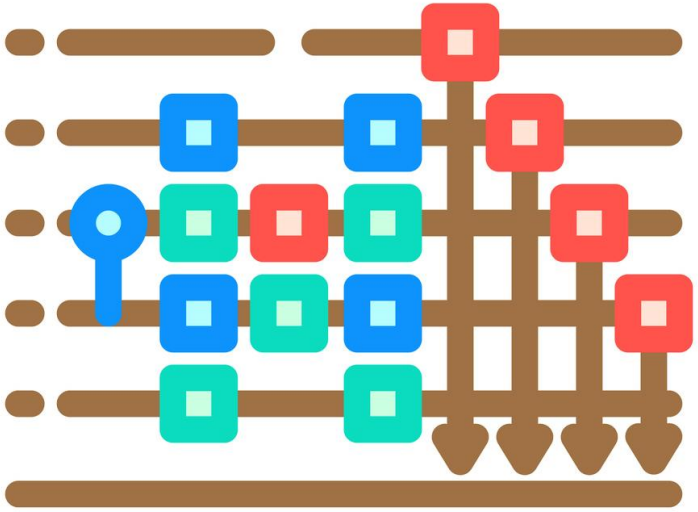


The Software Stack

- **SDKs and Applications**
  - Qiskit, Cirq, Q#
  - Domain-specific problem formulation
- **Circuit compilers and optimizers**
  - Translate logic into gate sequences
  - Reduce gate depth
  - Reduce qubit routing
- **Simulators**
  - Debugging
- **QEC/ Syndrome Decoding**
  - Machine learning models that interpret QEC syndromes in real-time
- **Hardware Access and Physical Control**
  - Cloud APIs to operational QPUs

SDKs and High Level Languages

- SDKs allow programming via familiar abstractions like Python, or in specialized languages “Q#”, shielding developers from quantum mechanics
- Qiskit, Cirq, and Pennylane are three structural libraries to build quantum logic
- Platforms can pioneer automated algorithm synthesis
  - Generate optimized circuit logic directly from high-level functional models



Compilers and Optimizers

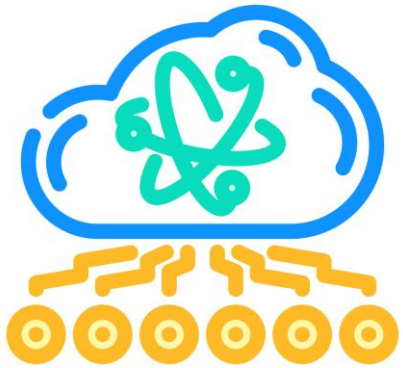
- Every QPU has a unique physical layout and limited connectivity
- Compiler maps and routes the circuit to fit the specific hardware graph
- Logical quantum circuit
  - Routing and mapping – assigning logical algorithms to specific physical qubits based on exact connectivity constraints of the target hardware
- Gate scheduling
  - Compressing and ordering operations to beat the decoherence clock
- Hardware-specific instructions

Quantum Simulators

- Classical software that mimics quantum behavior, essential for debugging, testing, and verifying logic without burning expensive QPU time
- Efficiently emulating quantum states on classical GPUs is an area of active patenting
- Formal Verification Frameworks
  - Mathematical techniques to prove that an optimized, hardware-specific circuit is identical to the original logical algorithm

Quantum-as-a-Service (QaaS)

- **Hardware Agnostic**
  - Cloud platforms use intermediate representations to abstract the hardware, allowing one SDK to target multiple competing physical modalities



- **Division of Labor**
  - Classical systems handle data preparation, I/O, and control
  - QPUs act as specialized accelerators for sub-routines
- **Hybrid Algorithms**
  - Frameworks like Variational Quantum Eigensolver (VGE) are designed specifically to run in a continuous classical-quantum feedback loop
- **IP Focus:** Innovations in dynamic job queuing, cross-platform transpilation, and quantum resource allocation

Real-World Use Case Domains



In Closing …

The Future is Being Drafted Today

- **Quantum is a stack**
  - Opportunities exist from the cryogenic plumbing to the algorithmic software.
- **Hardware is diverse**
  - The race is wide open.
- **Error correction is key**
  - Software algorithms that solve decoherence are a holy grail.
- **Your engineering and legal expertise are entirely translatable to the quantum realm.**

Any Questions?

Thank you

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