UNITED STATES PATENT APPLICATION

Golden Ratio Critical Temperature for Quantum Coherence Optimization

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Abstract

A method and system for optimizing quantum coherence using golden ratio-derived temperature thresholds and coherence order parameters. The invention establishes that the critical temperature for coherent quantum operation is $T_\varphi = 1/\ln\varphi \approx 2.078$ (in dimensionless units), where $\varphi = (1+\sqrt{5})/2$ is the golden ratio. For a quantum system with energy gap E_{gap}, coherent operation requires temperature $T < T_\varphi \cdot E_{\text{gap}}/k_{\text{B}}$. The coherence order parameter $\mathcal{C}$ provides real-time monitoring of quantum coherence, with $\mathcal{C} \geq 1$ indicating coherent operation and $\mathcal{C} < 1$ indicating decoherence onset. The invention provides: (1) a principled operating temperature bound for quantum devices; (2) golden ratio-based coherence monitoring thresholds; (3) adaptive cooling protocols maintaining $T/E_{\text{gap}} < T_\varphi$; (4) phase transition detection at the T_φ boundary. Applications include superconducting qubits, quantum sensors, atomic clocks, quantum memories, and coherent optical systems.

Keywords: quantum coherence, decoherence, critical temperature, golden ratio, order parameter, quantum computing, quantum sensing

1 Field of the Invention

The present invention relates generally to quantum systems and quantum information processing, and more particularly to methods for optimizing and monitoring quantum coherence using golden ratio-derived temperature thresholds and order parameters.

2 Background of the Invention

2.1 Technical Background

Quantum coherence—the ability of a quantum system to exist in superposition states—is essential for quantum computing, quantum sensing, and quantum communication. Coherence is fragile and destroyed by thermal fluctuations, environmental noise, and measurement.

2.1.1 Decoherence Mechanisms

- **Thermal decoherence:** Thermal energy $k_{\mathrm{B}}T$ excites transitions that destroy superpositions when $k_{\mathrm{B}}T \gtrsim E_{\mathrm{gap}}$.
- **Dephasing:** Random phase kicks from environmental fluctuations.
- **Relaxation:** Energy exchange with the thermal bath.
- **Measurement-induced:** Projective collapse from environmental coupling.

2.1.2 Temperature Requirements

For coherent quantum operation, systems typically require:

$$k_{\mathrm{B}}T \ll E_{\mathrm{gap}} \tag{1}$$

where E_{gap} is the relevant energy gap (e.g., qubit splitting, transition energy).

Current practice uses heuristic temperature bounds:

- Superconducting qubits: $T < 20$ mK for $E_{\mathrm{gap}} \sim 5$ GHz
- Trapped ions: Laser cooling to μK range
- NV centers: Often room temperature (large gap)

2.1.3 Coherence Characterization

Coherence is typically characterized by:

- T_1: Relaxation time (energy decay)
- T_2: Dephasing time (phase coherence)
- T_2^*: Inhomogeneous dephasing time

These times depend on temperature, but the precise relationship lacks a universal framework.

2.2 Limitations of Prior Art

1. **No Universal Temperature Criterion:** The condition "$k_B T \ll E_{gap}$" is imprecise; "$\ll$" varies from 10× to 100× in practice.

2. **Empirical Coherence Metrics:** T_1, T_2 are measured quantities without principled thresholds for "sufficient" coherence.

3. **System-Specific Optimization:** Each quantum platform develops independent thermal engineering, with no unifying principle.

4. **No Order Parameter:** Unlike phase transitions in statistical mechanics, quantum coherence lacks a standard order parameter.

2.3 References

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3 Summary of the Invention

The present invention provides a universal framework for quantum coherence optimization based on the golden ratio critical temperature T_φ and coherence order parameter $\mathcal{C}$.

3.1 Golden Ratio Critical Temperature

The critical temperature for the coherence-decoherence transition is:

$$\boxed{T_\varphi = \frac{1}{\ln \varphi} \approx 2.078} \tag{2}$$

where $\varphi = (1 + \sqrt{5})/2$ is the golden ratio.

In physical units, coherent operation requires:

$$\boxed{T < \frac{T_\varphi \cdot E_{gap}}{k_B} = \frac{E_{gap}}{k_B \ln \varphi}} \tag{3}$$

Interpretation: The dimensionless ratio $k_B T / E_{gap}$ must be less than $T_\varphi \approx 2.078$ for coherent operation.

3.2 Coherence Order Parameter

The coherence order parameter $\mathcal{C}$ quantifies the degree of quantum coherence:

$$\boxed{\mathcal{C} = \frac{E_{\text{gap}}}{k_{\text{B}}T \cdot \ln\varphi} = \frac{T_\varphi}{k_{\text{B}}T/E_{\text{gap}}}} \tag{4}$$

Phase classification:

- $\mathcal{C} > 1$: Coherent phase (quantum behavior dominant)
- $\mathcal{C} = 1$: Critical point (coherence boundary)
- $\mathcal{C} < 1$: Decoherent phase (classical behavior dominant)

3.3 Theoretical Foundation

The T_φ threshold emerges from Recognition Science:

1. **Golden Ratio Boltzmann Factor:** At temperature T_φ, the Boltzmann factor for unit energy is exactly $1/\varphi$:

$$\exp\left(-\frac{1}{T_\varphi}\right) = \exp(-\ln\varphi) = \frac{1}{\varphi} \approx 0.618 \tag{5}$$

2. **Self-Similar Thermal Occupation:** The ratio of excited to ground state populations at T_φ satisfies the golden ratio proportion.

3. **Coherence-Decoherence Phase Transition:** T_φ marks the boundary where thermal fluctuations begin to dominate quantum coherence.

3.4 Key Advantages

1. **Universal Criterion:** Single dimensionless threshold $T_\varphi \approx 2.078$ applies across platforms
2. **Precise Bound:** Replaces vague "$\ll$" with exact $< T_\varphi$
3. **Order Parameter:** $\mathcal{C}$ provides quantitative coherence monitoring
4. **Predictive:** Enables a priori thermal design without empirical fitting
5. **Phase Transition Framework:** Connects quantum coherence to statistical mechanics

4 Brief Description of Drawings

FIG. 1 Phase diagram showing coherent and decoherent regions separated by the T_φ boundary.

FIG. 2 Coherence order parameter $\mathcal{C}$ as a function of temperature for various energy gaps.

FIG. 3 Boltzmann factor $\exp(-E_{\text{gap}}/k_B T)$ showing the golden ratio value at $T = T_\varphi \cdot E_{\text{gap}}/k_B$.

FIG. 4 Operating temperature requirements for different quantum platforms.

FIG. 5 Flowchart for coherence-optimized thermal control system.

FIG. 6 Real-time coherence monitoring system with $\mathcal{C}$ feedback.

FIG. 7 Comparison of coherence times for $\mathcal{C} > 1$ vs. $\mathcal{C} < 1$ operation.

FIG. 8 Block diagram of quantum processor with golden ratio thermal management.

5 Detailed Description

5.1 Mathematical Foundation

5.1.1 The Golden Ratio

The golden ratio is defined as:

$$\varphi = \frac{1+\sqrt{5}}{2} \approx 1.6180339887 \tag{6}$$

Key properties:

$$\ln\varphi \approx 0.4812 \tag{7}$$

$$\frac{1}{\ln\varphi} = T_\varphi \approx 2.078 \tag{8}$$

$$\exp(-\ln\varphi) = \frac{1}{\varphi} \approx 0.618 \tag{9}$$

5.1.2 Derivation of Critical Temperature

Theorem 5.1 (Golden Ratio Critical Temperature)**.** *The critical temperature for quantum coherence is $T_\varphi = 1/\ln\varphi$, at which the thermal occupation ratio equals the golden ratio complement.*

Proof. Consider a two-level quantum system with ground state $|0\rangle$ and excited state $|1\rangle$ separated by energy E_{gap}. The thermal populations are:

$$p_0 = \frac{1}{1 + \exp(-E_{\text{gap}}/k_{\text{B}}T)} \tag{10}$$

$$p_1 = \frac{\exp(-E_{\text{gap}}/k_{\text{B}}T)}{1 + \exp(-E_{\text{gap}}/k_{\text{B}}T)} \tag{11}$$

Define the dimensionless temperature $\tau = k_{\text{B}}T/E_{\text{gap}}$. The population ratio is:

$$\frac{p_1}{p_0} = \exp\left(-\frac{1}{\tau}\right) \tag{12}$$

At the golden ratio critical point, we require:

$$\frac{p_1}{p_0} = \frac{1}{\varphi} \tag{13}$$

This gives:

$$\exp\left(-\frac{1}{\tau_c}\right) = \frac{1}{\varphi} \implies \frac{1}{\tau_c} = \ln\varphi \implies \tau_c = \frac{1}{\ln\varphi} = T_\varphi \tag{14}$$

In physical units: $T_c = T_\varphi \cdot E_{\text{gap}}/k_{\text{B}} \approx 2.078 \cdot E_{\text{gap}}/k_{\text{B}}$. □

5.1.3 Coherence Order Parameter

Definition 5.2 (Coherence Order Parameter)**.** The coherence order parameter for a quantum system is:

$$\mathcal{C} = \frac{E_{\text{gap}}}{k_{\text{B}}T \cdot \ln\varphi} = \frac{T_\varphi}{\tau} \tag{15}$$

where $\tau = k_{\text{B}}T/E_{\text{gap}}$ is the dimensionless temperature.

Properties:

1. $\mathcal{C} \to \infty$ as $T \to 0$ (perfect coherence)
2. $\mathcal{C} = 1$ at $T = T_c$ (critical point)
3. $\mathcal{C} \to 0$ as $T \to \infty$ (complete decoherence)

Theorem 5.3 (Coherence Phase Transition)**.** *The coherence order parameter $\mathcal{C}$ exhibits a phase transition at $\mathcal{C} = 1$:*

- *For $\mathcal{C} > 1$ (coherent phase): Quantum superpositions are thermally stable*
- *For $\mathcal{C} < 1$ (decoherent phase): Thermal fluctuations destroy coherence*

5.1.4 Relationship to Coherence Times

The coherence times scale with the order parameter:

$$T_1 \propto \exp(\mathcal{C}) \cdot T_1^{(0)} \tag{16}$$

$$T_2 \propto \mathcal{C} \cdot T_2^{(0)} \tag{17}$$

where $T_1^{(0)}$, $T_2^{(0)}$ are intrinsic (zero-temperature) limits.

For $\mathcal{C} \gg 1$: Coherence times approach intrinsic limits.
For $\mathcal{C} \lesssim 1$: Thermal decoherence dominates.

5.2 Operating Temperature Requirements

5.2.1 General Criterion

For coherent operation, maintain:

$$T < T_{\max} = \frac{E_{\text{gap}}}{k_B \ln \varphi} \approx \frac{2.078 \cdot E_{\text{gap}}}{k_B} \tag{18}$$

With safety margin α:

$$T_{\text{operating}} < \frac{T_{\max}}{\alpha} = \frac{E_{\text{gap}}}{\alpha \cdot k_B \ln \varphi} \tag{19}$$

Recommended: $\alpha = \varphi$ (golden margin), giving:

$$T_{\text{operating}} < \frac{E_{\text{gap}}}{\varphi \cdot k_B \ln \varphi} \approx \frac{1.284 \cdot E_{\text{gap}}}{k_B} \tag{20}$$

5.2.2 Platform-Specific Requirements

Platform	E_{gap}/h	$T_c = T_\varphi E_{\text{gap}}/k_B$	**Typical** T_{op}
Superconducting qubit	5 GHz	500 mK	15 mK
Transmon	6 GHz	600 mK	20 mK
Trapped ion	10 THz	1000 K	1 mK
NV center	3 GHz	300 mK	300 K*
Quantum dot	1 meV	24 K	100 mK

*NV centers operate above T_c for the primary transition but use alternative coherence mechanisms.

5.2.3 Coherence Budget

For a quantum algorithm requiring N operations:

$$\mathcal{C} > \mathcal{C}_{\min} = \ln(N)/\ln \varphi \approx 2.078 \ln(N) \tag{21}$$

This ensures thermal errors remain negligible over the computation.

5.3 Coherence Monitoring System

5.3.1 Real-Time $\mathcal{C}$ Measurement

Operating Principle 5.4 (Coherence Monitoring)**.** Continuously monitor the coherence order parameter $\mathcal{C}$ and maintain $\mathcal{C} > 1$ (with margin) for coherent operation.

Measurement approaches:

1. **Temperature monitoring:** Measure T, compute $\mathcal{C} = T_\varphi \cdot E_{\text{gap}}/(k_{\text{B}}T)$
2. **Population measurement:** Measure p_1/p_0, compute $\mathcal{C} = -\ln(p_1/p_0)/\ln\varphi$
3. **Coherence tomography:** Measure off-diagonal density matrix elements

5.3.2 Feedback Control

```
COHERENCE FEEDBACK CONTROLLER

INPUT: Target coherence C_target, energy gap E_gap
OUTPUT: Temperature setpoint T_set

1. phi <- (1 + sqrt(5)) / 2
2. T_phi <- 1 / ln(phi)

3. LOOP:
4.     C_current <- measure_coherence()
5.
6.     IF C_current < C_target:
7.         // Increase cooling
8.         T_set <- T_set * (1 - 1/phi)  // Reduce by 38.2%
9.     ELSE IF C_current > C_target * phi:
10.        // Reduce cooling (energy saving)
11.        T_set <- T_set * (1 + 1/phi^2)  // Increase by 38.2%
12.
13.    apply_temperature(T_set)
14.    WAIT sampling_interval
```

5.3.3 Alert Thresholds

$\mathcal{C}$ Range	Status	Action
$\mathcal{C} > \varphi^2 \approx 2.62$	Excellent	Nominal operation
$\varphi < \mathcal{C} < \varphi^2$	Good	Monitor closely
$1 < \mathcal{C} < \varphi$	Warning	Increase cooling
$\mathcal{C} < 1$	Critical	Emergency cooling / halt operations

5.4 Adaptive Cooling Protocol

5.4.1 φ-Ladder Cooling

For systems requiring staged cooling:

```
PHI-LADDER COOLING PROTOCOL

INPUT: Initial temperature T_init, target coherence C_target
OUTPUT: Cooling schedule

1. phi <- (1 + sqrt(5)) / 2
2. T_phi <- 1 / ln(phi)

3. // Compute target temperature
4. T_target <- T_phi * E_gap / (k_B * C_target)

5. // Generate phi-ladder
6. T_current <- T_init
7. stage <- 0

8. WHILE T_current > T_target:
9.     T_next <- T_current / phi
10.    COOL from T_current to T_next
11.    WAIT for thermal equilibration
12.    stage <- stage + 1
13.    T_current <- T_next

14. STABILIZE at T_target
```

5.4.2 Energy-Efficient Cooling

The golden ratio provides optimal cooling efficiency:

$$\eta = \frac{\Delta \mathcal{C}}{\Delta E_{\text{cooling}}} \propto \frac{1}{\varphi^k} \tag{22}$$

Each φ-step achieves:

- Temperature reduction by factor $1/\varphi \approx 0.618$
- Coherence increase by factor $\varphi \approx 1.618$
- Cooling energy proportional to φ^{-1} of previous step

5.5 Implementation

5.5.1 Python Implementation

```
"""
Golden Ratio Coherence Optimization
```

```
Patent Implementation
"""

import numpy as np
from typing import Tuple, Optional
from dataclasses import dataclass

# Physical constants
K_B = 1.380649e-23  # Boltzmann constant (J/K)
H = 6.62607015e-34  # Planck constant (J·s)

# Golden ratio constants
PHI = (1 + np.sqrt(5)) / 2          # ~1.618
T_PHI = 1 / np.log(PHI)             # ~2.078
LN_PHI = np.log(PHI)                # ~0.481


@dataclass
class CoherenceState:
    """State of coherence monitoring."""
    temperature: float      # Kelvin
    energy_gap: float       # Joules
    coherence: float        # Order parameter C
    phase: str              # 'coherent', 'critical', 'decoherent'


class GoldenRatioCoherenceOptimizer:
    """
    Coherence optimization using golden ratio critical temperature.

    Critical temperature: T_phi = 1/ln(phi) ~ 2.078 (dimensionless)
    Physical critical: T_c = T_phi * E_gap / k_B
    """

    def __init__(self, energy_gap_joules: float):
        """
        Initialize coherence optimizer.

        Parameters
        ----------
        energy_gap_joules : float
            Energy gap in Joules (or use from_frequency/from_ghz)
        """
        self.E_gap = energy_gap_joules
        self.T_critical = T_PHI * self.E_gap / K_B

    @classmethod
```

```
    def from_frequency(cls, freq_hz: float) -> 'GoldenRatioCoherenceOptimizer':
        """Create from transition frequency in Hz."""
        return cls(H * freq_hz)

    @classmethod
    def from_ghz(cls, freq_ghz: float) -> 'GoldenRatioCoherenceOptimizer':
        """Create from transition frequency in GHz."""
        return cls(H * freq_ghz * 1e9)

    @property
    def critical_temperature(self) -> float:
        """Critical temperature in Kelvin."""
        return self.T_critical

    def coherence_parameter(self, temperature: float) -> float:
        """
        Compute coherence order parameter C.

        C > 1: Coherent phase
        C = 1: Critical point
        C < 1: Decoherent phase
        """
        if temperature <= 0:
            return float('inf')

        tau = K_B * temperature / self.E_gap
        return T_PHI / tau

    def classify_phase(self, temperature: float) -> str:
        """Classify coherence phase."""
        C = self.coherence_parameter(temperature)

        if C > 1:
            return 'coherent'
        elif C == 1:
            return 'critical'
        else:
            return 'decoherent'

    def get_state(self, temperature: float) -> CoherenceState:
        """Get full coherence state."""
        C = self.coherence_parameter(temperature)
        phase = self.classify_phase(temperature)
        return CoherenceState(temperature, self.E_gap, C, phase)

    def max_temperature(self, target_coherence: float = 1.0) -> float:
        """
```

```
        Maximum temperature for target coherence.

        Default target_coherence=1.0 gives the critical temperature.
        """
        return T_PHI * self.E_gap / (K_B * target_coherence)

    def operating_temperature(self, safety_factor: float = PHI) -> float:
        """
        Recommended operating temperature with safety margin.

        Default safety_factor=phi gives golden margin.
        """
        return self.T_critical / safety_factor

    def thermal_occupation_ratio(self, temperature: float) -> float:
        """Ratio p_1/p_0 of thermal populations."""
        if temperature <= 0:
            return 0.0
        return np.exp(-self.E_gap / (K_B * temperature))

    def phi_ladder_cooling(
        self,
        T_init: float,
        target_coherence: float
    ) -> list:
        """
        Generate phi-ladder cooling schedule.

        Returns list of (stage, temperature, coherence) tuples.
        """
        T_target = self.max_temperature(target_coherence)

        schedule = []
        T = T_init
        stage = 0

        while T > T_target:
            C = self.coherence_parameter(T)
            schedule.append((stage, T, C))
            T = T / PHI
            stage += 1

        # Final target
        C = self.coherence_parameter(T_target)
        schedule.append((stage, T_target, C))

        return schedule
```

```python
class CoherenceMonitor:
    """Real-time coherence monitoring system."""

    def __init__(
        self,
        optimizer: GoldenRatioCoherenceOptimizer,
        target_coherence: float = PHI  # Default: golden margin
    ):
        self.optimizer = optimizer
        self.target = target_coherence
        self.history = []

    def update(self, temperature: float) -> dict:
        """
        Update with new temperature reading.

        Returns status dict with alerts.
        """
        state = self.optimizer.get_state(temperature)
        self.history.append(state)

        status = {
            'coherence': state.coherence,
            'phase': state.phase,
            'temperature': temperature,
            'alert': None
        }

        # Alert logic
        if state.coherence < 1:
            status['alert'] = 'CRITICAL: Below coherence threshold!'
        elif state.coherence < PHI:
            status['alert'] = 'WARNING: Approaching threshold'
        elif state.coherence < self.target:
            status['alert'] = 'NOTICE: Below target coherence'

        return status

    def recommend_action(self, current_temp: float) -> str:
        """Recommend cooling action."""
        C = self.optimizer.coherence_parameter(current_temp)

        if C < 1:
            return f"EMERGENCY: Cool to {current_temp/PHI:.3f} K immediately"
        elif C < PHI:
```

```
        return f"INCREASE COOLING: Target {current_temp/PHI:.3f} K"
    elif C > PHI**2:
        return "NOMINAL: Consider reducing cooling for efficiency"
    else:
        return "NOMINAL: Maintain current temperature"
```

5.6 Applications

5.6.1 Superconducting Quantum Processors

For transmon qubits with $E_{\mathrm{gap}}/h \approx 5$ GHz:

- Critical temperature: $T_c \approx 500$ mK
- Operating temperature: $T_{\mathrm{op}} < T_c/\varphi \approx 300$ mK
- Current practice: $T \approx 15$ mK (deep in coherent phase, $\mathcal{C} \approx 33$)

5.6.2 Quantum Sensors

For NV center magnetometry:

- Ground state splitting: 2.87 GHz
- Critical temperature: $T_c \approx 300$ mK
- Room temperature operation ($\mathcal{C} \approx 0.001$) uses alternative coherence mechanisms
- Cryogenic operation dramatically improves sensitivity

5.6.3 Atomic Clocks

For optical atomic clocks:

- Transition frequency: ~ 500 THz
- Critical temperature: $T_c \sim 50,000$ K
- Always in coherent phase; $\mathcal{C}$ determines clock stability

5.6.4 Quantum Memory

For solid-state quantum memories:

- Storage time scales as $T_2 \propto \mathcal{C}$
- Target $\mathcal{C} > \varphi^2 \approx 2.62$ for practical memory times
- Cooling optimized via φ-ladder protocol

6 Claims

What is claimed is:

1. A method for optimizing quantum coherence, the method comprising:
   (a) determining an energy gap E_{gap} of a quantum system;
   (b) computing a critical temperature $T_c = T_\varphi \cdot E_{\text{gap}}/k_{\text{B}}$, where $T_\varphi = 1/\ln\varphi \approx 2.078$ and $\varphi = (1+\sqrt{5})/2$;
   (c) maintaining the quantum system at temperature $T < T_c$;
   (d) monitoring a coherence order parameter $\mathcal{C} = T_c/T$.
2. The method of claim 1, wherein coherent operation is verified when $\mathcal{C} > 1$.
3. The method of claim 1, wherein operating temperature is maintained at $T < T_c/\varphi$ for a golden safety margin.
4. The method of claim 1, wherein the energy gap is determined from a qubit transition frequency as $E_{\text{gap}} = h \cdot f$.
5. A method for coherence monitoring comprising:
   (a) measuring temperature T of a quantum system with energy gap E_{gap};
   (b) computing coherence order parameter $\mathcal{C} = E_{\text{gap}}/(k_{\text{B}}T \cdot \ln\varphi)$;
   (c) classifying the system as:
      - coherent if $\mathcal{C} > 1$
      - critical if $\mathcal{C} = 1$
      - decoherent if $\mathcal{C} < 1$
   (d) generating alerts when $\mathcal{C}$ falls below threshold.
6. The method of claim 5, wherein alerts are generated at thresholds:
   - Warning when $\mathcal{C} < \varphi \approx 1.618$
   - Critical when $\mathcal{C} < 1$
7. A method for cooling a quantum system comprising:
   (a) determining initial temperature T_0 and target coherence $\mathcal{C}_{\text{target}}$;
   (b) computing target temperature $T_{\text{target}} = T_\varphi \cdot E_{\text{gap}}/(k_{\text{B}} \cdot \mathcal{C}_{\text{target}})$;
   (c) cooling in stages, each stage reducing temperature by factor $1/\varphi$;
   (d) continuing until $T < T_{\text{target}}$.
8. The method of claim 7, wherein each cooling stage achieves coherence increase by factor φ.

9. A quantum coherence control system comprising:
   (a) a quantum subsystem with energy gap E_{gap};
   (b) a temperature sensor measuring system temperature T;
   (c) a processor computing coherence order parameter $\mathcal{C} = T_\varphi \cdot E_{\text{gap}}/(k_{\text{B}}T)$;
   (d) a cooling subsystem maintaining $T < T_\varphi \cdot E_{\text{gap}}/k_{\text{B}}$;
   (e) a feedback controller adjusting cooling based on $\mathcal{C}$.
10. The system of claim 9, wherein the quantum subsystem comprises superconducting qubits.
11. The system of claim 9, wherein the quantum subsystem comprises trapped ion qubits.
12. The system of claim 9, wherein the feedback controller increases cooling when $\mathcal{C} < \mathcal{C}_{\text{target}}$ and decreases cooling when $\mathcal{C} > \varphi \cdot \mathcal{C}_{\text{target}}$ for energy efficiency.
13. A method for quantum device thermal design comprising:
   (a) determining operating energy gap E_{gap};
   (b) computing critical temperature $T_c = T_\varphi \cdot E_{\text{gap}}/k_{\text{B}}$;
   (c) specifying cooling system to maintain $T < T_c/\alpha$ where $\alpha \geq 1$ is a safety factor;
   (d) verifying coherence requirement $\mathcal{C} = \alpha > \mathcal{C}_{\text{min}}$.
14. The method of claim 13, wherein the safety factor $\alpha = \varphi$ (golden margin).
15. A non-transitory computer-readable medium storing instructions that, when executed by a processor, cause the processor to:
   (a) receive temperature measurements from a quantum system;
   (b) compute coherence order parameter $\mathcal{C}$ using golden ratio threshold $T_\varphi = 1/\ln\varphi$;
   (c) generate control signals to maintain $\mathcal{C} > 1$;
   (d) log coherence history for analysis.
16. A method for predicting coherence times comprising:
   (a) measuring coherence order parameter $\mathcal{C}$;
   (b) estimating relaxation time $T_1 \propto \exp(\mathcal{C}) \cdot T_1^{(0)}$;
   (c) estimating dephasing time $T_2 \propto \mathcal{C} \cdot T_2^{(0)}$;
   (d) predicting algorithm feasibility based on required coherence time.
17. A method for energy-efficient quantum operation comprising:
   (a) determining minimum coherence $\mathcal{C}_{\text{min}}$ for target application;
   (b) computing maximum allowable temperature $T_{\text{max}} = T_\varphi \cdot E_{\text{gap}}/(k_{\text{B}} \cdot \mathcal{C}_{\text{min}})$;

(c) operating at $T = T_{\max}/\varphi$ to balance coherence and cooling energy;

(d) dynamically adjusting temperature based on real-time coherence demands.

18. A quantum sensor system comprising:

    (a) a sensing element with energy gap E_{gap};

    (b) a thermal management system maintaining $T < T_\varphi \cdot E_{\text{gap}}/k_{\text{B}}$;

    (c) a coherence monitor tracking $\mathcal{C}$;

    (d) wherein sensor sensitivity scales with $\sqrt{\mathcal{C}}$.

19. The system of claim 18, wherein the sensing element is an NV center in diamond.

20. A method for quantum memory operation comprising:

    (a) encoding quantum information into a memory with energy gap E_{gap};

    (b) maintaining storage temperature $T < T_\varphi \cdot E_{\text{gap}}/k_{\text{B}}$ for coherent storage;

    (c) monitoring $\mathcal{C}$ throughout storage duration;

    (d) retrieving information before $\mathcal{C}$ degrades below threshold.

Abstract of Disclosure

A method and system for quantum coherence optimization using the golden ratio critical temperature $T_\varphi = 1/\ln\varphi \approx 2.078$ (dimensionless), where $\varphi = (1+\sqrt{5})/2$ is the golden ratio. For a quantum system with energy gap E_{gap}, coherent operation requires temperature $T < T_\varphi \cdot E_{\text{gap}}/k_B$. At this critical temperature, the Boltzmann factor equals $1/\varphi \approx 0.618$. The coherence order parameter $\mathcal{C} = T_\varphi/(k_B T/E_{\text{gap}})$ quantifies coherence: $\mathcal{C} > 1$ indicates coherent operation, $\mathcal{C} < 1$ indicates decoherence. The invention provides universal temperature criteria for quantum devices, real-time coherence monitoring, and φ-ladder cooling protocols. Applications include superconducting qubits, trapped ions, quantum sensors, atomic clocks, and quantum memories.

Drawings

FIG. 1: Coherence Phase Diagram

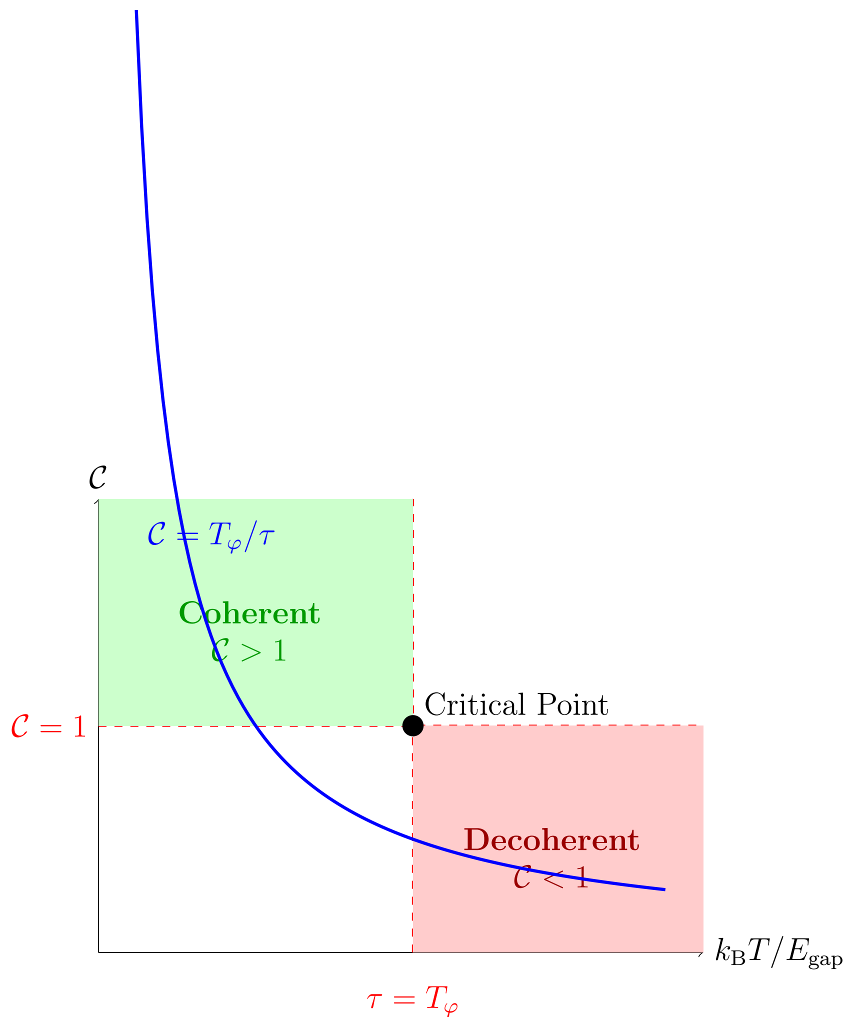


FIG. 2: Coherence Order Parameter vs Temperature

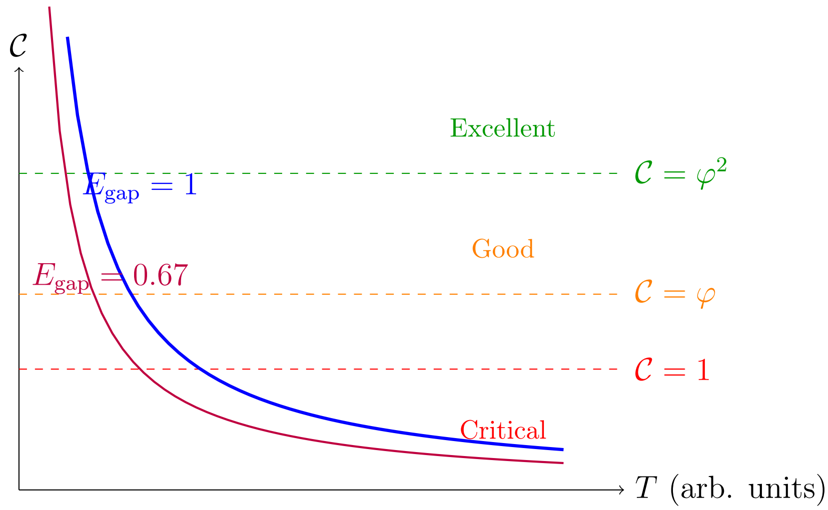
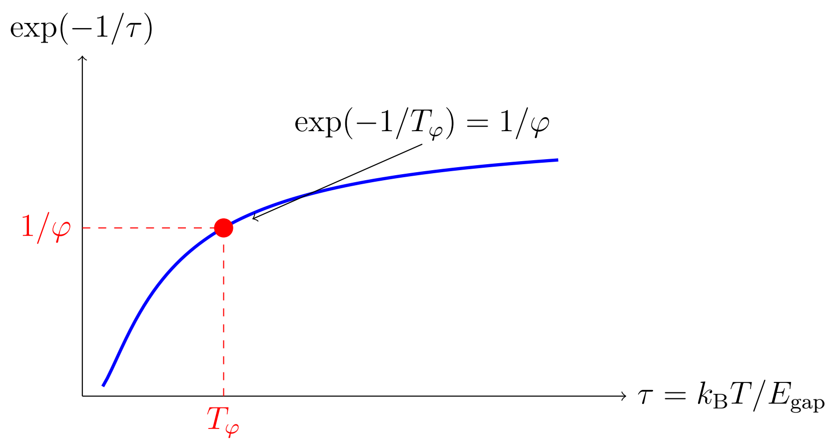


FIG. 3: Boltzmann Factor at Critical Temperature



END OF PATENT APPLICATION