# Topology Phase Persistence: Five Additional HHF Predictions on IBM Quantum Hardware

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## Abstract

We present empirical validation of five additional Hydrogen Holographic Fractal (HHF) predictions using a comprehensive topology phase persistence suite executed on IBM Quantum hardware. This follow-on experiment extends initial HHF validation by testing advanced circuit topology effects that cannot be reproduced through classical simulation.

Predictions Tested:

- P1: Topology-Locked Phase Frequencies — stable spectral components in recursive circuits
- P2: Minimal Hydrogen-Analog Unit Advantage — single vs multi-axis irrational phase coherence
- P3: Circuit Chemical Families — behavioral clustering of circuit motifs
- P4: Grammar-Constrained Superiority — grammar rules vs random/optimized circuits
- P5: Positive Coherence Yield Regimes — PEFF-proxy positive coherence gain

All experiments were executed on IBM Quantum hardware (ibm_fez) with 1024 measurement shots per circuit, demonstrating statistically significant topology-dependent phase behavior.

Keywords: quantum topology, circuit families, phase persistence, HHF validation, IBM Quantum, fractal circuits

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# 1. Introduction

## 1.1 Background and Scientific Context

Following initial validation of HHF predictions through boundary-phase persistence testing [1], this experiment suite addresses five additional hypotheses concerning advanced quantum circuit topology effects. The HHF framework predicts that recursive circuit architectures exhibit fundamental advantages over classical topologies when executed on quantum hardware.

## 1.2 Extended HHF Predictions

P1 — Topology-Locked Phase Frequencies

> Recursive (fractal-embedded) circuits exhibit stable spectral phase components across hardware noise that do not appear in flat or randomized topologies.

P2 — Minimal Hydrogen-Analog Unit Advantage

> Circuits dominated by a single irrational phase axis ($\sqrt{2}$, φ, e) retain coherence longer than multi-axis phase circuits.

P3 — Circuit Chemical Families

> Circuit motifs cluster into behavioral families with consistent empirical properties independent of qubit mapping.

P4 — Grammar-Constrained Superiority

> Circuits generated by holographic fractal grammar rules outperform random or optimizer-generated circuits at equal depth and gate count.

P5 — Positive Coherence Yield Regimes

Certain recursive circuits temporarily exhibit positive coherence gain per entropy produced (PEFF-proxy > 0).

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# 2. Experimental Methodology

## 2.1 Hardware Execution Platform

- Backend: IBM Quantum (ibm_fez)
- Qubits: 3 per circuit
- Shots: 1024 measurements per circuit
- Irrational Phases: √2, φ, e

## 2.2 Circuit Topology Classes

P1 Topologies:

- Recursive Fractal: Self-embedded hierarchical phase structures
- Flat Linear: Sequential phase gates with nearest-neighbor coupling
- Ring Topology: Cyclic connections with periodic boundaries
- Randomized: Stochastic connectivity patterns

P2 Phase Axis Configurations:

- Single Axis √2, φ, e — circuits using one irrational phase
- Multi-Axis — circuits combining all three

P3 Circuit Families:

- Linear Chain, Ring, Recursive Tree, Grammar-Closed

P4 Grammar Constraints:

- Grammar Constrained, Grammar Recursive, Random Equal Depth, Qiskit Optimized

P5 PEFF Candidates:

- Recursive PEFF Candidate, Flat PEFF Control, Random PEFF Control

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# 3. Results and Analysis

## 3.1 Execution Summary

- Predictions Tested: 5
- Circuit Classes Evaluated: 15+
- Hardware Executions: 5 prediction suites
- Data Points Collected: Full measurement distributions

## 3.2 Prediction-Specific Results

#### P1: Topology-Locked Phase Frequencies

- Methodology: Fourier spectral analysis across topologies
- Findings: Recursive circuits demonstrated stable spectral peaks; flat linear circuits showed diffuse spectra; ring topologies periodic structure; randomized stochastic patterns
- Implications: Evidence for hardware-dependent phase locking mechanisms

#### P2: Minimal Unit Advantage

- Methodology: Coherence decay comparison single vs multi-axis
- Findings: Single-axis circuits maintained coherence longer; $\sqrt{2}$-based circuits optimal; multi-axis accelerated decoherence

- Implications: Minimal phase unit dominance suggests fundamental hardware-phase coupling

**P3: Circuit Chemical Families**

- Methodology: PCA/t-SNE on circuit behavioral feature vectors
- Findings: Distinct clustering of linear, ring, recursive, and grammar-closed circuits
- Implications: Quantum circuits form natural behavioral families analogous to chemical compound classes

**P4: Grammar-Constrained Superiority**

- Methodology: Metrics: coherence, entropy, mutual information
- Findings: Grammar-constrained circuits outperformed random; recursive grammar circuits showed superior information retention
- Implications: Holographic grammar captures fundamental quantum circuit design principles

**P5: Positive Coherence Yield Regimes**

- Methodology: PEFF-proxy (ΔMI/ΔEntropy) over circuit evolution
- Findings: Recursive PEFF candidate circuits showed temporary positive yield; control circuits monotonic decay
- Implications: Certain recursive topologies can achieve positive coherence yield, challenging standard decoherence models

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# 4. Discussion

## 4.1 HHF Framework Validation

All five predictions aligned with HHF expectations, showing systematic topology-dependent advantages, grammar-constrained superiority, and positive coherence regimes.

### 4.2 Hardware-Dependent Phenomena

- Spectral phase locking unique to recursive topologies
- Hardware-phase coupling in single-axis circuits
- Behavioral clustering independent of classical metrics
- Positive coherence yield contradicting standard T1/T2 models

### 4.3 Scientific Implications

- Quantum Circuit Design: Topology is fundamental; recursive structures confer inherent advantages
- HHF Framework: Predictions supported, strengthening holographic quantum information principles
- Hardware Characterization: Provides new methods for quantifying topology-dependent behavior

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## 5. Conclusions

This topology phase persistence suite empirically supports five advanced HHF predictions. Recursive and grammar-constrained circuits consistently exhibit enhanced performance, confirming topology-dependent quantum processing advantages.

Key Achievements:

- ✅ Five HHF predictions validated
- ✅ Topology-dependent phase effects demonstrated
- ✅ Circuit behavioral families identified
- ✅ Grammar-constrained superiority established
- ✅ Positive coherence yield observed

Future Directions:

- Multi-backend replication
- Larger-scale circuit investigations
- Real-time topology optimization
- Integration with quantum error correction

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## References

[1] HHF Initial Validation Study — Boundary-Phase Persistence Test

[2] Qiskit Development Team (2023). Qiskit: An Open-source Framework for Quantum Computing

[3] IBM Quantum Systems Documentation

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