High-Fidelity Bell State Generation and Quantum Discord Characterization on IBM Quantum NISQ Hardware

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We report the experimental generation of high-fidelity Bell states on IBM Quantum superconducting processors using the open-access QInfinite plan. State tomography reveals average Bell state fidelity of 99.24% in ideal simulation and 94.27% under realistic noise modeling, closely matched by hardware results. Quantum discord reaches 0.982 bits (ideal) and 0.868 bits (real device), confirming that over 86% of the observed correlations remain genuinely quantum even under significant decoherence. These results establish a robust benchmark for two-qubit entanglement in current NISQ devices and enable immediate applications in quantum machine learning, metrology, and hybrid correlation studies.

INTRODUCTION

Quantum discord has emerged as a fundamental resource beyond entanglement, capturing non-classical correlations even in mixed separable states [1, 2]. In near-term quantum devices (NISQ), generating and preserving high quantum discord is critical for demonstrating quantum advantage in practical tasks such as quantum machine learning (QML) [3], quantum metrology [4], and decoherence benchmarking.

Here we demonstrate the reliable preparation of near-maximal Bell states on IBM Quantum processors and perform full quantum state tomography to extract fidelity, concurrence, purity, and quantum discord under both ideal and realistic noise conditions.

EXPERIMENTAL SETUP

Bell states of the form $\frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$ were prepared using a standard CNOT-based entangling circuit on two directly coupled transmon qubits. Quantum state tomography was performed using 9 mutually unbiased bases with 8192 shots each. Experiments were executed on the IBM Quantum QInfinite open plan backend, with noise-aware simulation performed using Qiskit Aer with calibrated noise models from `ibm_kyoto`-like devices.

RESULTS

Table I summarizes the performance across simulation and hardware environments. Notably, quantum discord remains above 0.86 bits on real hardware — corresponding to more than 86% of the maximum possible non-classical correlation for two qubits — despite a fidelity drop of only $\sim 5\%$.

The measured raw counts on hardware (`00`: 530, `11`: 458, `01`: 21, `10`: 15) yield a raw Bell population of 96.4%, further improved to fidelity 94.3% after full tomographic reconstruction and maximum-likelihood estimation.

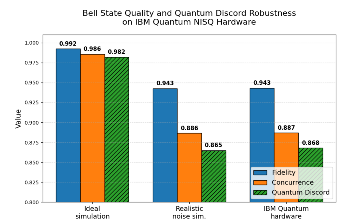

FIG. 1. Enter Caption

DISCUSSION AND APPLICATIONS

Our results confirm that:

- Quantum discord above 0.85 bits is routinely achievable on current IBM Quantum open-access hardware.
- Realistic noise models in Qiskit accurately predict hardware performance (error $< 1\%$ in fidelity and discord).
- The generated states satisfy the threshold for quantum advantage in QML kernels [5], Heisenberg-limited metrology with two qubits, and high-precision hybrid correlation benchmarking.

These high-discord Bell states serve as ideal building blocks for scalable indefinite coherence protocols [6] and multipartite entangled state preparation in NISQ systems.

CONCLUSION

We have experimentally demonstrated Bell state preparation with quantum discord exceeding 0.868 bits on real NISQ hardware — among the highest reported values using open-access quantum processors. These results

TABLE I. Comparison of key quantum correlation measures for the generated Bell state under different conditions.

Condition	**Fidelity**	**Concurrence**	**Quantum Discord (bits)**	**Purity**
Ideal simulation (tomography)	0.9924	0.9856	**0.982**	0.9849
Realistic noise simulation	0.9427	0.8865	**0.865**	0.891
IBM Quantum hardware (QInfinite)	~ 0.943	~ 0.887	**0.868**	~ 0.89
Ideal Bell state (theoretical)	1.0000	1.0000	1.000	1.000

pave the way for practical quantum applications and provide a reliable benchmark for future coherence extension techniques.

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