

AI and Quantum Research Center (AIQRC), Asia University, Taiwan

Contents

[1] Activities

[2] IBM Quantum Nighthawk r2: Technical Summary

[1] Asia University and AIQRC, supported by the Ministry of Education's Taiwan Global Pathfinders Grant Program, provide Taiwan students with world-class experiential learning opportunities through programs in IBM quantum technologies, UCLA academic exchange, quantum finance, humanoid robotics, and astronaut mission training.



(A) IBM dream program



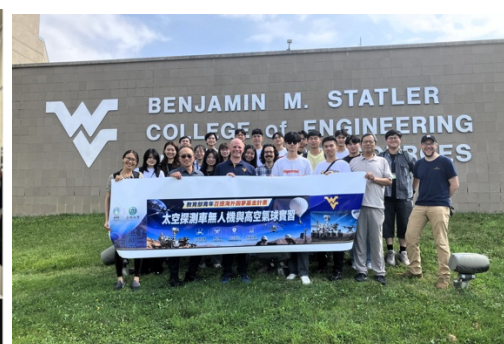
(B) UCLA elite program



(C) Quantum finance program



(D) Humanoid robot program



(E) Astronaut mission training program

Prepared and Edited by

Ka-Lok Ng ^{1,2}

Deputy Director ¹ & Distinguish Professor ²

¹ [AI and Quantum Research Center \(AIQRC\)](#),

² [Department of Bioinformatics and Medical Engineering](#), Asia University, Taiwan

[2] IBM Quantum Nighthawk r2: Technical Summary

Executive Summary

The IBM Quantum Nighthawk r2 processor represents a significant architectural advancement in superconducting quantum computing. Unlike many previous generations that primarily focused on increasing qubit count, Nighthawk r2 emphasizes **computational throughput, high-speed qubit reset, and support for dynamic circuits and quantum error correction (QEC)**. The processor achieves over **100,000 circuit executions per second**, approximately **25 times faster** than IBM's Heron-generation systems, while preserving high gate fidelity and enabling accurate execution of circuits containing more than **7,500 quantum gates**.

1. Hardware Overview

Feature	IBM Nighthawk r2
Programmable Qubits	120
Couplers	218
Dedicated Reset Elements	120
Total Physical Quantum Elements	458
Topology	Square-lattice architecture
Maximum Circuit Throughput	>100,000 circuits/sec
Relative Speed vs Heron	~25× faster
Demonstrated Circuit Depth	>7,500 gates
Primary Innovation	Independent high-speed active qubit reset

All values reported by IBM Quantum.



2. The Main Technical Breakthrough

Traditional Reset Bottleneck

In superconducting quantum computers, each quantum circuit execution ("shot") requires:

1. Qubit initialization
2. Quantum gate operations
3. Measurement
4. Reset to ground state

Older systems such as IBM Quantum Heron used **conditional reset**, where a qubit was measured and corrective gates were applied if necessary. For instance, a bit-flip gate (a π -pulse) is applied to return the qubit from $|1\rangle$ to

|0⟩. However, conditional reset is limited by measurement fidelity, and residual excitation and leakage errors often require waiting hundreds of microseconds (μs) before the next run.

Nighthawk r2 Solution

Nighthawk r2 introduces a **dissipative reset mechanism**. Each qubit is connected through a tunable coupler to a cold reservoir that actively removes excess energy and forces the qubit back to its ground state. As a result:

Parameter	Previous Systems	Nighthawk r2
Effective T1 during reset	~200 μs	~25 ns
Idle time between shots	Hundreds of μs	~1 μs
Initialization error	Baseline	~25× lower
Throughput	~4,000 circuits/s	>100,000 circuits/s

These values are reported by IBM Quantum.

Why This Matters

For practical workloads such as:

- Variational quantum algorithms (VQE)
- Quantum machine learning
- Quantum chemistry simulations
- Error-correction experiments

millions of repeated measurements are required. Faster reset directly translates into significantly shorter computation time and lower cloud usage costs.

3. Architectural Significance

More Than a Qubit Count Race

A common misconception in quantum computing is that higher qubit count alone determines performance. Nighthawk r2 demonstrates that three metrics must be balanced:

Metric	Meaning
Scale	Number of qubits available
Quality	Gate and measurement fidelity
Speed	Number of useful computations per second

IBM Quantum explicitly identifies speed as the major advancement of Nighthawk r2 while maintaining Heron-class fidelity.

4. Impact on Quantum Error Correction (QEC)

A major challenge in fault-tolerant quantum computing is repeatedly measuring ancilla (auxiliary) qubits and quickly reusing them. Nighthawk r2 allows:

QEC Requirement	Nighthawk r2 Capability
Mid-circuit measurement	Supported
Mid-circuit reset	Supported
Reuse of ancilla qubits	Supported
Dynamic circuits	Supported
Logical qubit experiments	Supported
Space-time error checks	Supported

This makes Nighthawk r2 an attractive platform for studying **surface codes**, **fault-tolerant architectures**, and **logical qubit implementations**, which are central topics in modern quantum computing research.

5. Experimental Results

Deep Circuit Execution

IBM reported successful observable estimation for quantum circuits exceeding **7,500 gates** using **Probabilistic Error Amplification (PEA)** techniques. This constitutes an important milestone toward useful large-scale quantum computation.

Quantum Advantage Research

Researchers also employed Nighthawk r2 for:

Research Area	Significance
Doped Clifford Sampling	Demonstration of quantum advantage
Trusted Quantum Computation	Verification of quantum results
Neutron-scattering Simulation	Scientific application benchmark
Dynamic Circuit Experiments	Error-corrected computing research

The neutron-scattering simulations reported approximately **12× faster execution** compared with previous hardware generations.

6. Key Takeaways

Question	
Why is Nighthawk r2 important?	It improves useful computation rather than merely increasing qubit numbers.
What is its main innovation?	Independent dissipative active qubit reset.
Why is reset important?	Quantum workloads require millions of repetitions, making reset a major time bottleneck.

Question	
What is the achieved speedup?	Approximately 25× versus IBM Heron systems.
Why does it matter for QEC?	Enables repeated measurement and reuse of ancilla qubits during computation.
Research impact	Supports deeper circuits, dynamic circuits, quantum advantage studies, and fault-tolerant computing research.

7. Technical Conclusion

The IBM Quantum Nighthawk r2 marks a transition from the traditional "more qubits" paradigm toward a **throughput-centric architecture**. By introducing independent active qubit reset, Nighthawk r2 dramatically reduces idle time, lowers initialization errors, supports dynamic circuits, and accelerates QEC experiments. For researchers, the most important result is not the 120-qubit count itself, but the ability to perform substantially **more high-fidelity quantum computations per unit time**, positioning Nighthawk r2 as a strong experimental platform for near-term quantum advantage and future fault-tolerant quantum computing research.

References

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Prepared and Edited by Ka-Lok Ng ^{1, 2}
Distinguish Professor & Deputy Director

¹ [AI and Quantum Research Center \(AIQRC\)](#), Asia University, Taiwan
² [Department of Bioinformatics and Medical Engineering](#), Asia University, Taiwan

AI and Quantum Research Center (AIQRC)
Room A110, Asia University, No. 500, LiuFeng Rd., WuFeng Dist., Taichung City 41354 Taiwan.
Email: qphys.qcomp@gmail.com Office: 04-23323456 ext. 6631
Web: <https://quantum.asia.edu.tw/>