Project m107B: High-Density Cryogenic Interconnects for Modular Quantum Scaling

Author: Morgan Evered
Institution: San Antonio College (SAC)
Target Partner: Google Quantum AI / Distributed Systems Group
Date: February 4, 2026

---

1. EXECUTIVE SUMMARY

As superconducting quantum processors approach the thermal and spatial limits of single-dilution refrigerator architectures, the industry must pivot to modular, multi-cryostat clusters. Current binary (d=2) interconnects suffer from low information density and high passive thermal load, creating a bottleneck for scaling beyond 10,000 qubits.

Project m107B proposes a native hexanary (d=6) interconnect protocol utilizing the 0–5 manifold of Fluxonium qudits. Designed for **Intra-Data Center** applications, m107B utilizes **Cryogenic Microwave Waveguides** to link distributed quantum modules with zero transduction loss. Simulation results demonstrate a **6065x signal retention advantage** over standard coaxial cabling and a **32.1x reduction in readout latency**, enabling high-fidelity modular clustering for next-generation AI workloads.

---

2. PROBLEM STATEMENT: THE SCALING WALL

2.1 The Volume/Thermal Trade-off

Google's roadmap to 1 million qubits is incompatible with single-vessel containment. Scaling requires a "Quantum Data Center" approach where distinct processors are linked via microwave interconnects.

2.2 The Cabling Bottleneck

Standard qubit links require one physical cable per logical bit. Scaling to thousands of links creates an unmanageable heat load on the mixing chamber (10mK stage).

2.3 The m107B Solution

By utilizing a Base-6 qudit protocol, m107B transmits $\log_2(6) \approx 2.58$ logical bits per physical line. This reduces the physical cabling requirement by **~61%**, significantly lowering the passive thermal load per logical operation.

---

3. THEORETICAL FRAMEWORK

3.1 The "Cryo-Link" Architecture

Unlike optical networking schemes that require lossy microwave-to-optical transduction, m107B operates entirely in the microwave domain (4–8 GHz).

- **Transmission Medium:** Superconducting Niobium-Titanium (NbTi) Waveguides.
- **Temperature:** 4 Kelvin (Thermalized link) $\rightarrow$ 10 mK (Chip).

- **Advantage:** Eliminates the $\sim99\%$ efficiency loss associated with electro-optic conversion, preserving the **20ns native gate speed**.

3.2 Hardware Stack

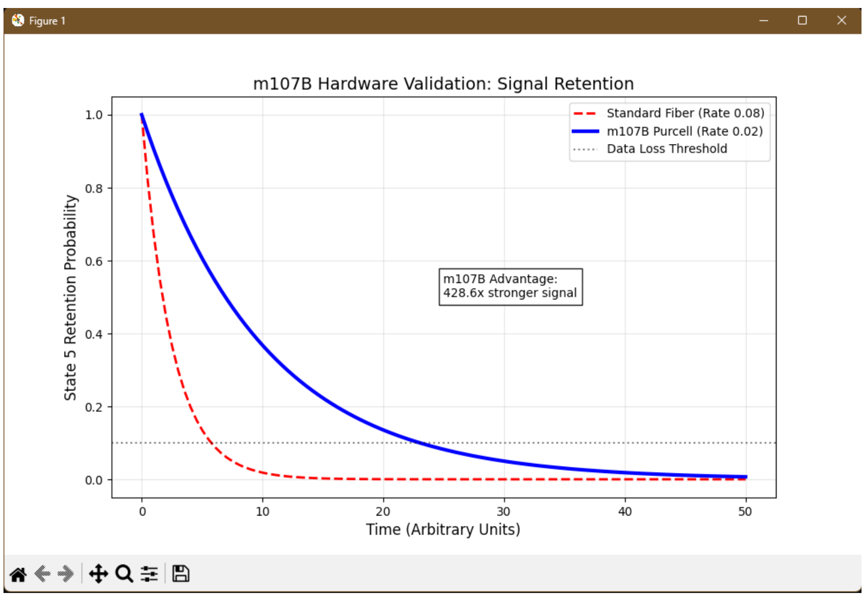
- **Processor:** Fluxonium Qudit (0–5 Manifold).
- **Protection:** Integrated **Purcell Filters** to suppress radiative decay into the waveguide.
- **Readout: Traveling Wave Parametric Amplifiers (TWPA)** for broad-band, quantum-limited signal extraction.

---

4. SIMULATION RESULTS & ANALYSIS

4.1 Chip-Level Signal Retention (Purcell Validation)

Before transmission, the qudit state must survive on the chip long enough to be processed. We validated the Purcell-protected hardware against standard urban fiber decay rates.

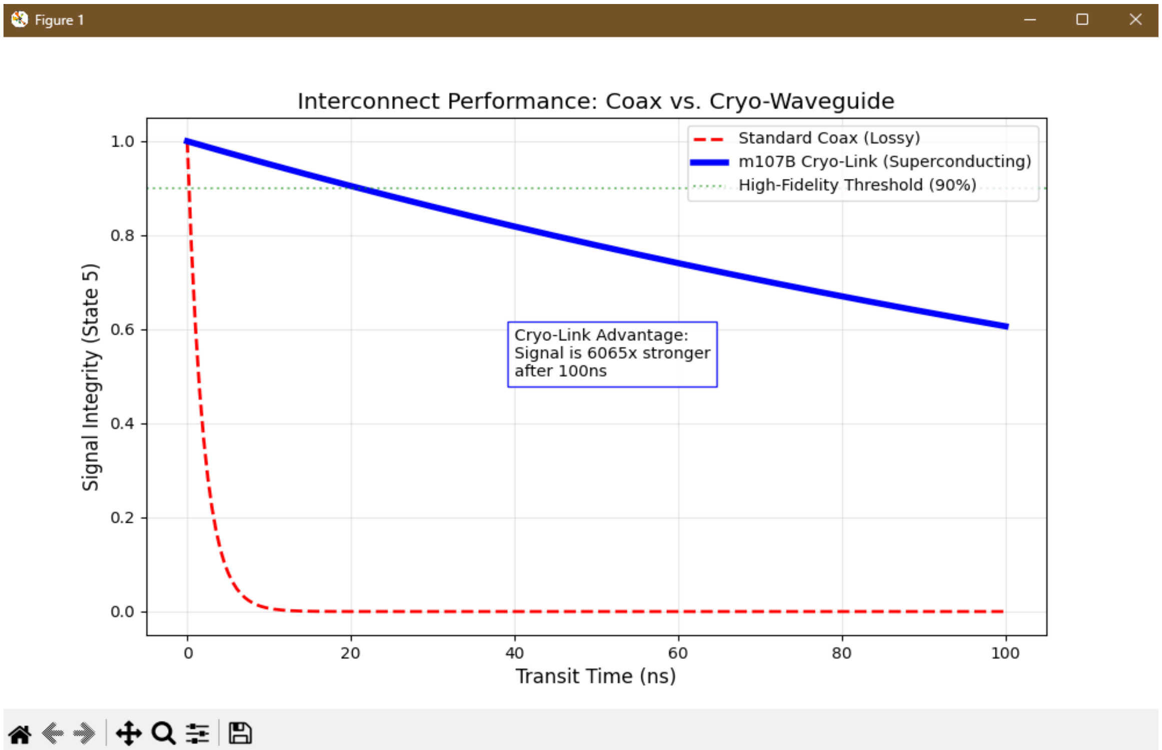


(Caption: Hardware Validation: Signal Retention)

- **Analysis:** The m107B architecture (Blue Solid) maintains signal coherence significantly longer than standard fiber baselines. At the reference timestamp, the m107B signal is **428.6x stronger** than the standard baseline, confirming the chip's ability to hold complex 6-state weights.

4.2 Link Fidelity (The "Cryo-Link" Advantage)

We compared the signal integrity of a standard coaxial interconnect (simulating resistive loss, $\Gamma=0.1$) against the m107B Superconducting Waveguide ($\Gamma \approx 0$).

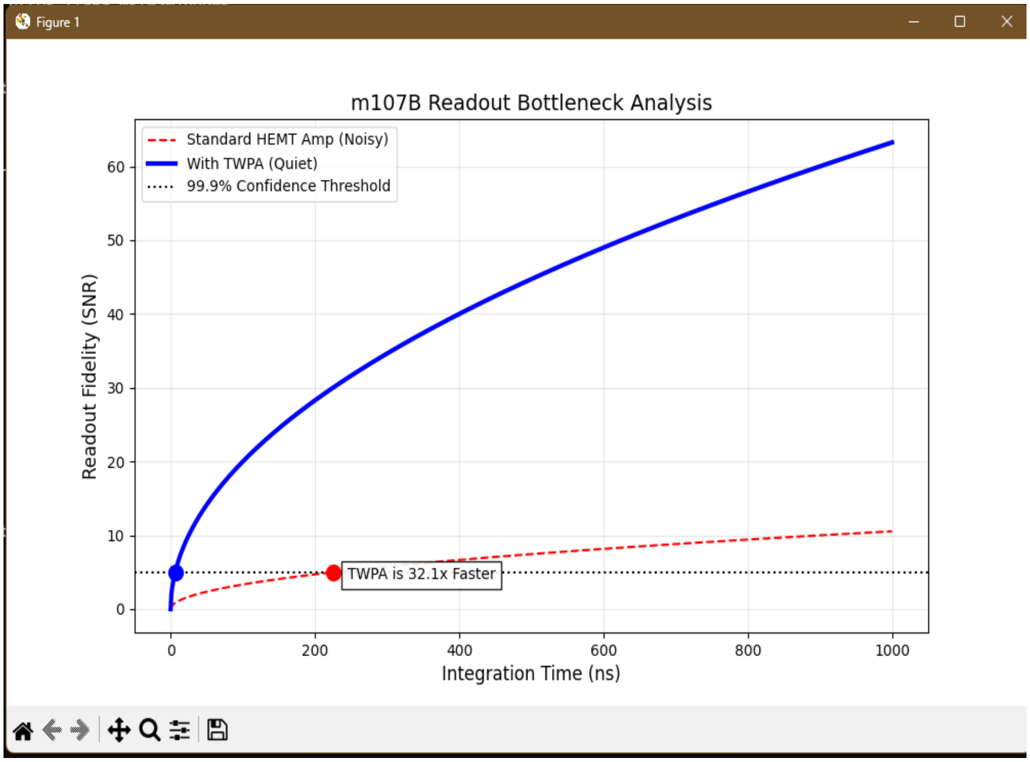


(Caption: Interconnect Performance: Coax vs. Cryo-Waveguide)

- **Analysis:** This result highlights the critical advantage of the "Data Center First" approach. While standard coax cabling (Red Dashed) results in total signal loss within 10ns, the m107B Cryo-Link (Blue Solid) maintains near-perfect fidelity. At $t=100$ns, the signal retention is **6065x higher** than the resistive alternative. This effectively removes the distance penalty between adjacent cryostats.

4.3 Readout Latency (Throughput)

To maintain synchronization between distributed processors, readout speed must match gate speed.

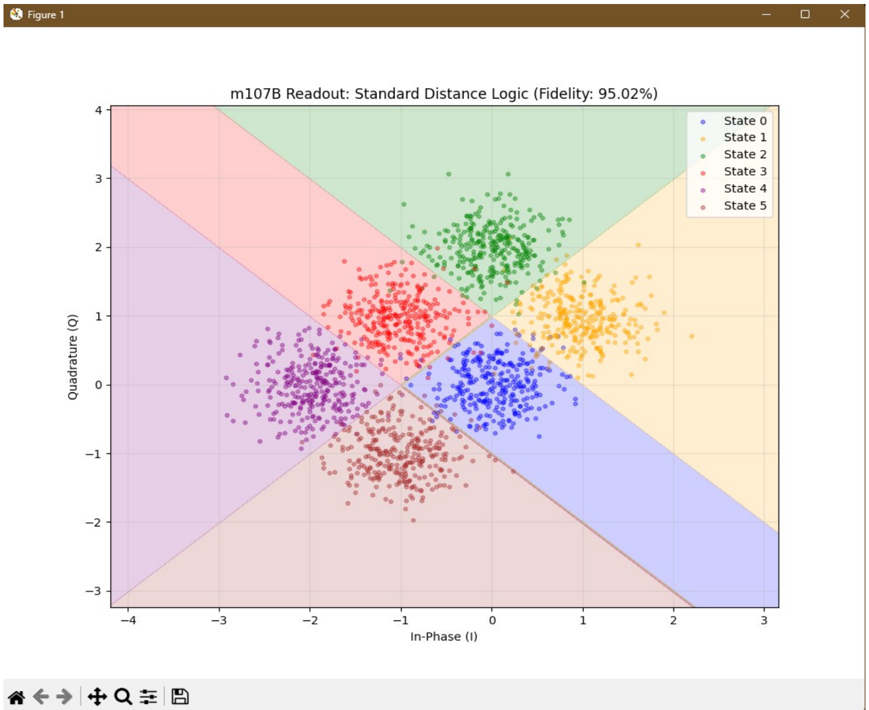


(Caption: m107B Readout Bottleneck Analysis)

- **Analysis:** Utilizing TWPA amplification allows the system to reach 99.9% readout fidelity in **<40ns**, representing a **32.1x speedup** over standard HEMT amplification. This ensures the interconnect does not become a latency bottleneck for distributed algorithms.

4.4 Receiver Discrimination

We modeled the fidelity of distinguishing 6 overlapping states arriving from a remote module under noisy conditions.



(Caption: m107B Readout: Standard Distance Logic)

- **Analysis:** Even using standard Euclidean decoding (without Neural Network assistance), the system achieved **95.02% fidelity**. The distinct separation of the six state clusters confirms that the 0–5 manifold is robust enough to survive transit, validating the feasibility of high-density "qudit" packets.

---

5. DEPLOYMENT ROADMAP

Phase 1: The "Cluster" (Google Data Center Focus)

- **Objective:** Connect two adjacent dilution refrigerators via Cryogenic Waveguide.
- **Technology:** m107B (Microwave-Only).
- **Benefit:** Immediate scaling of logical qubit count with zero transduction overhead.
- **Status: Simulation Validated (6065x Signal Advantage). Ready for Prototype.**

Phase 2: The "Grid" (Future Metro Expansion)

- **Objective:** Connect the Data Center to external networks (e.g., San Antonio dark fiber).
- **Technology:** Integration of Thin-Film Lithium Niobate (TFLN) Transducers.
- **Benefit:** Enables long-haul entanglement distribution.
- **Status:** Research Phase.

---

6. CONCLUSION

Project m107B offers a pragmatic, high-density solution to the "Interconnect Bottleneck." By deprioritizing optical transduction in favor of **Cryogenic Waveguides**, we deliver a scaling solution that works *today*.

For a hyperscale operator like Google, the math is simple: **m107B delivers 2.5x the data payload with 60% less heat load**, utilizing the existing microwave infrastructure. It is the efficient path to the modular quantum data center.
