

Independent Quantum-Research Audit of Gaussian-Controlled Rotation: Core Result Reproduced, Comparison Caveats Remain

An analytical and numerical reproducibility audit of a defined part of Non-Abelian Quantum Signal Processing, not a validation of the entire paper or quantum hardware.

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Summary

Haivian independently derived the Gaussian-controlled-rotation (GCR) cancellation mechanism and reproduced four selected public numerical curves from the work of Shraddha Singh, Baptiste Royer and Steven M. Girvin. Within the specified ideal Gaussian-input model, the central error-suppression result is supported. Across 640 saved comparison values, the largest absolute difference from our independently written calculation was about 1.25×10^{-14} .

The audit also found comparison and presentation issues. GCR reduces qubit-readout failure in the checked examples, but it does not uniformly improve joint oscillator-qubit fidelity over the BB1 baseline. Some printed benchmark values and metric labels need clarification. We therefore report reproduction of the bounded core result with explicit comparison caveats, not a blanket successful validation of the full publication.

The paper was published on 15 October 2026 in Physical Review X 16, 041018, following acceptance on 25 September 2026, with DOI 10.1103/7jwl-k8xg. This additional third-party research audit neither replaces that peer review nor claims the work was previously unreviewed.

What we audited

Our scientific target was the two-pulse GCR primitive and the noiseless Gaussian-input comparison with the four-pulse BB1 sequence in Figure 3(a) and Table II. The frozen arXiv v6 manuscript defines the pulse, input state, angle and metrics. Its downloaded PDF has 39 actual pages and SHA-256 `a38a7e0ecea32ba0049364d970384ac4bc0986238fe8aa4cc463c4eea17c997d`. The PDF's internal date is 30 September 2026, whereas arXiv v6 metadata says 28 September and its comments describe a different page count. We identify the exact bytes and use their equation numbers rather than silently mix editions.

All equation-specific and localized presentation findings in this report concern that frozen arXiv v6 PDF. We have not performed an equation-by-equation comparison against the final APS edition and do not assert that these issues persist there.

We inspected the complete manuscript to define this boundary, with detailed derivation and visual checks concentrated on the primitive, error analysis and comparison figures. The paper's later results on state preparation, noisy GKP quantum error correction, multimode gates and phase estimation were not independently reproduced by this audit.

The public numerical artifacts came from the authors' code and data repository at commit `298f15adf98fcb5973146fa0f818293a5827d5f7`. We inspected the relevant notebook cells as data, checked the MIT license and file identities, and compared against saved numeric arrays. We did not execute the author notebook or reproduce its entire workflow.

The supported cancellation mechanism

The model combines an oscillator with a qubit. Position and momentum obey $[x, p] = i/2$. The input oscillator is a normalized real Gaussian of known center $\alpha > 0$ and known width $\Delta > 0$; the qubit begins in its prescribed ground state. The two gates act in the stated order.

Define $y = (x - \alpha)/\Delta$ and $\chi = \theta \Delta / (2\alpha)$, where θ is the physical target rotation angle. The Gaussian probability distribution of y has variance $1/4$. In position space, the momentum-controlled pulse translates the Gaussian conditionally on the qubit. That exact translation, followed by the position-controlled rotation, cancels the linear unwanted spin amplitude.

Our direct integration gives the following exact continuum expressions for this particular input and pulse:

$$P_{\text{fail}} = [1 - \exp(-\chi^2) - \exp(-\chi^2/2)\sin(\chi^2)]/2$$

$$F_{\text{joint}} = \exp(-\chi^2/2)[1 + \sin(\chi^2/2)].$$

Consequently,

$$P_{\text{fail}} = 5\chi^6/48 - 5\chi^8/96 + O(\chi^{10})$$

and

$$1 - F_{\text{joint}} = \chi^4/8 - \chi^6/48 + O(\chi^8).$$

These independently support the central leading GCR error orders. The calculation uses well-defined translations of Gaussian states, not a global operator-norm expansion for arbitrary unbounded observables. It is state-sensitive: it does not prove the same cancellation for an arbitrary qubit input, arbitrary non-Gaussian oscillator state, or unknown Gaussian width.

Independent numerical reproduction

We wrote a separate calculation using direct Gaussian quadrature and explicit two-by-two qubit rotations. The author data were not fitted to construct our calculation. We checked quadrature orders 32, 64 and 128 and independently propagated GCR in truncated oscillator spaces of dimensions 32, 64, 96, 128 and 192.

The four saved curves contain 160 displacement values each, ranging from $\alpha = 2$ to 9.95 , with $\theta = \pi/2$ and $\Delta = 1$. Maximum absolute differences were below 2.5×10^{-15} for both GCR curves and BB1 failure probability, and below 1.25×10^{-14} for BB1 joint infidelity. These are floating-point agreement figures, not interval-certified error bounds.

Representative independently computed values are:

α	GCR failure	BB1 failure	GCR joint infidelity	BB1 joint infidelity
2	0.00035336	0.00400373	0.00289492	0.00421862
4	0.000005855	0.00008589	0.00018459	0.00009340
10	0.00000002437	0.0000003754	0.000004751	0.0000004246

The $\alpha = 10$ row is an additional direct quadrature point, not one of the saved arrays' 160 points, whose last displacement is 9.95 .

Cutoff convergence matters. At $\alpha = 6$, truncation to 32 oscillator levels retains only about 23% of its initial coherent-state probability mass (squared norm) and gives a completely misleading result despite normalized final simulation states. Increasing the cutoff restores agreement with the continuum calculation. This audit does not establish convergence of the authors' later, more complex circuits.

Intentional adverse controls also behaved differently from the correct pulse. At $\alpha=2$, removing the correction raised failure probability to about 0.0371; reversing its sign raised it to about 0.1426. Reversing gate order, using an inconsistent BB1 angle convention and severely undertruncating the oscillator likewise degraded the result. These controls make the check sensitive to implementation choices; they are not purported corrections to the submitted paper.

What needs clarification

Failure is not total infidelity. Qubit-readout failure asks whether the target qubit outcome is wrong. Joint fidelity asks whether both oscillator and qubit match the target. Oscillator fidelity after qubit reset sums both spin branches, while postselected fidelity conditions on success. These quantities are not generally interchangeable. The notebook variables named `reset_fid` and `reset_b` actually compute joint-state infidelity. For this special GCR input, parity makes joint and reset fidelity coincide; for BB1 they differ slightly.

The comparative coefficient needs its metric. A separate fresh-eyes Pauli-product expansion found an approximately 1.61499 coefficient for BB1 failure probability and 1.84570 for joint infidelity in the literal main-text 90-degree convention. Thus the printed rounded 1.85 matches the latter, not the former. Under those definitions, the asymptotic failure-probability ratio is about 15.50, not 18.5. Appendix half-angle labels must be transformed consistently with χ ; simply changing an angle name cannot identify different operational metrics.

Table II needs an approximation label. Its BB1 entries near 0.007 are compatible with a leading-order estimate $1.85\chi^6$ at $\alpha=2$. They are not the exact finite- α values of the specified sequence or the saved Figure 3 data, which are about 0.0040 and 0.0042. This is a comparison/approximation correspondence issue; it does not show that the four-pulse implementation or saved data are wrong.

GCR offers a tradeoff, not uniform dominance. In the checked range it has fewer qubit failures and two rather than four conditional gates. But at $\alpha=4$ and 10 its joint infidelity is higher than BB1's. The differing χ^4 and χ^6 orders explain why a favorable comparison near $\alpha=2$ cannot extend uniformly to arbitrarily large α . Figure 3 itself displays this distinction. Shorter nominal pulse duration also does not establish better performance on noisy hardware.

Our review additionally identified localized printed sign, higher-order normalization and nonzero-momentum convention issues. Factoring the main pulse leaves a negative position-error sign, unlike the literal sign printed in Appendix B6. The exact unitary Gaussian calculation does not require the parameter-dependent renormalization introduced in Appendix B12-B13, although their quotient reproduces the relevant failure terms through χ^8 . With $[x, p]=i/2$, a physical momentum displacement β uses $\exp(2i\beta x)$; the printed nonzero-momentum phase and compensation need a consistent β definition. We did not run a nonzero-momentum benchmark and do not claim this audit settles that extension.

Scope, review and trust limits

The one owner numerical run finished in 2.38 seconds on an existing local CPU, without installing dependencies, executing author code, using a VPS or purchasing compute. A direct continuum derivation and a different finite-Fock representation agreed for the targeted primitive. The numerical comparisons depend on ordinary floating-point arithmetic and retained Python, NumPy and native linear-algebra libraries; there was no clean-room toolchain rebuild, formal proof-assistant kernel check or independent quantum-hardware experiment.

Distinct-agent fresh-eyes review used the same AI provider. The reviewer disclosed seeing the owner's proposed GCR formulas before deriving its own checks, so this was not a formula-blind exercise. Findings and disagreements were frozen before reconciliation. This is not external human peer review, independent institutional accreditation, author endorsement or an affiliation with OpenAI. Haivian's audit service and publication share organizational control.

Conclusion: the defined Gaussian/prepared-ancilla GCR cancellation and selected numerical curves are reproducible. The benchmark and presentation caveats are material and remain part of the result. Full-paper correctness, experimental advantage, universal-input guarantees and later application claims are outside this third-party quantum-research audit.

Sources and evidence

- Exact arXiv v6 manuscript and version history.
- Original manuscript PDF.
- Physical Review X publication record and journal DOI.
- Frozen author code/data edition.

Public audit evidence identities accompany this report. We publish original analysis and link to primary sources; no third-party paper or raw author bundle is republished here.

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