Geometry- and Phase-Gated Suppression of Parasitic Recognition in Quantum Devices

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Field

This disclosure relates to quantum information devices and control, and more particularly to methods, apparatus, and control software that suppress spurious measurement/decoherence channels by using geometry and temporal phase gating derived from an intrinsic recognition threshold.

Background

Quantum devices are sensitive to unintended couplings that act as partial measurements, degrading coherence and causing crosstalk. Existing mitigation includes shielding, filtering, detuning, and time-multiplexing, but lacks a principled angular threshold for when recognition (measurement-like extraction) is feasible at a given interaction budget.

Summary

We disclose a threshold-based operating doctrine for quantum devices. Let the kernel-level action versus sensor angle be $A(\theta) = -\ln(\sin\theta)$ for $\theta \in (0, \frac{\pi}{2}]$. For a finite action budget $A_{\max} > 0$, define the minimal admissible angle

$$\theta_{\min}(A_{\max}) := \arcsin\left(e^{-A_{\max}}\right).$$

Channels with effective recognition angle $\theta < \theta_{\min}$ are infeasible at the given budget and are therefore suppressed; channels with $\theta \geq \theta_{\min}$ are feasible. Devices are operated such that (i) non-target couplings remain sub-threshold (idle geometry), (ii) target readout/control transitions are made supra-threshold *only within* permitted phase windows of a discrete cadence (phase gating), and (iii) the effective budget is reduced during idle and raised locally for readout.

Brief Description of the Drawings

- Fig. 1 illustrates a spherical-cap blind cone of half-angle $\theta_{\min}$ about a collinear axis (non-target directions), marking infeasible directions at a given budget.
- Fig. 2 shows $A(\theta) = -\ln(\sin\theta)$ and threshold markers $\theta = \theta_{\min}(A_{\max})$ for several budgets.

Detailed Description of Embodiments

Threshold and gating. For a device channel with effective sensor angle θ, the recognition weight scales as $w = \exp(-2A(\theta)) = (\sin\theta)^2$ in the kernel-dominated regime. For a given $A_{\max}$, the device is configured so that non-target channels satisfy $\theta < \theta_{\min}(A_{\max})$ during idle, while the intended detector/coupler is actuated to $\theta \geq \theta_{\min}(A_{\max})$ only within designated phase windows of a discrete cadence (e.g., eight-tick). Budget steering (filters, attenuation, detuning, shielding) increases $\theta_{\min}$ during idle and reduces it locally during readout.

Superconducting embodiment. A transmon or cavity device with adjustable readout/feedline coupler orientation relative to a mode axis. Packaging and coupler pads are oriented so parasitic couplings to non-target modes have $\theta < \theta_{\min}$ in idle. A controller actuates tunable couplers or switches to achieve $\theta \geq \theta_{\min}$ in permitted windows for readout.

Trapped-ion embodiment. Raman/readout beams are incident at angles engineered so spectator ions see sub-threshold angles; gate/readout beams are phase-gated and steered to supra-threshold angles for the targeted ion only within windows.

Integrated photonics embodiment. Directional couplers and polarization elements are oriented so non-target ports see sub-threshold angles. Readout ports are brought above threshold during windows by thermo-optic or electro-optic tuning.

Controller/scheduler. A timing controller maintains a window set and phases operations to those windows, while tracking budget state and geometry state to satisfy the feasibility predicate (angle and time). The controller can auto-calibrate by measuring spurious recognition vs. θ and adjusting toward sub-threshold during idle.

What is claimed is:

1. A method of operating a quantum information device, comprising:
   a. configuring at least one non-target coupling to have an effective recognition angle θ less than a threshold $\theta_{\min}$, where $\theta_{\min} = \arcsin(e^{-A_{\max}})$ for a finite action budget $A_{\max} > 0$;
   b. actuating at least one target detector or coupler such that its effective recognition angle satisfies $\theta \geq \theta_{\min}$ only within permitted phase windows of a discrete cadence; and
   c. adjusting the effective action budget by at least one of filtering, attenuation, detuning, or shielding during idle so as to increase $\theta_{\min}$, thereby suppressing parasitic recognition.
2. The method of claim 1, wherein the discrete cadence comprises an eight-tick cadence and the phase windows are residue classes modulo eight.
3. The method of claim 1, wherein configuring the recognition angle comprises orienting a waveguide, coupler, antenna, or optical beam at a selected angle relative to a device mode axis.
4. The method of claim 1, wherein actuating the target detector or coupler comprises enabling a tunable coupler, switch, or beam steering element to achieve $\theta \geq \theta_{\min}$ only within the permitted windows.

5. The method of claim 1, further comprising measuring spurious recognition probability versus angle and iteratively adjusting geometry to maintain $\theta < \theta_{\min}$ for non-target couplings.
6. The method of claim 1, wherein the device is a superconducting transmon or cavity system, and configuring comprises orienting readout coupler pads and package geometries so that non-target modes are sub-threshold during idle.
7. The method of claim 1, wherein the device is a trapped-ion system, and configuring comprises selecting beam incidence and numerical aperture such that spectator ions remain sub-threshold during idle.
8. The method of claim 1, wherein the device is an integrated photonic system, and configuring comprises setting directional couplers and polarization such that non-target ports remain sub-threshold during idle.
9. An apparatus comprising:
   a. a quantum element having at least one mode axis;
   b. an adjustable coupler or beam path arranged at a configurable angle θ relative to the mode axis; and
   c. a controller configured to maintain $\theta < \theta_{\min}$ for non-target couplings during idle and to actuate $\theta \geq \theta_{\min}$ for a target coupling only within permitted phase windows, where $\theta_{\min} = \arcsin(e^{-A_{\max}})$ for a budget $A_{\max} > 0$.
10. The apparatus of claim 9, wherein the controller further adjusts at least one of filtering, attenuation, detuning, or shielding during idle to increase $\theta_{\min}$.
11. A system comprising a plurality of quantum elements and a scheduler configured to phase-align operations to a window set, maintain non-target angles below $\theta_{\min}$ device-wide during idle, and raise selected channels above $\theta_{\min}$ only in the window set.
12. A non-transitory computer-readable medium storing instructions that, when executed by a controller, cause the controller to: (i) determine $\theta_{\min} = \arcsin(e^{-A_{\max}})$ from a budget parameter; (ii) maintain geometry states with $\theta < \theta_{\min}$ for non-target couplings; and (iii) schedule operations so that $\theta \geq \theta_{\min}$ only within permitted phase windows.

Abstract

Methods, apparatus, systems, and software for suppressing parasitic recognition in quantum devices by enforcing a budget-dependent angular threshold $\theta_{\min} = \arcsin(e^{-A_{\max}})$ and discrete phase gating. Non-target couplings are kept sub-threshold during idle; target couplings are raised above threshold only within permitted phase windows. The approach reduces spurious measurement and crosstalk across superconducting, trapped-ion, and photonic platforms with low overhead and is compatible with quantum error correction.

Figures

Fig. 1. Spherical-cap blind cone on S^2 with half-angle $\theta_{\min}$ about a collinear axis; red region indicates infeasible (sub-threshold) directions.

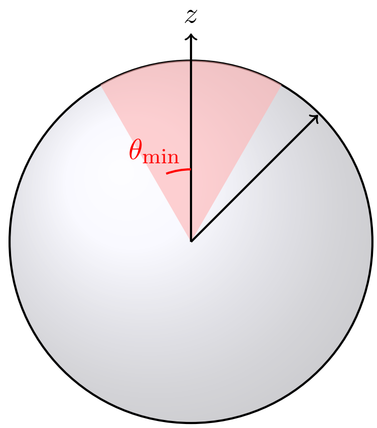

Figure 1: Blind cone illustration.

Fig. 2. Kernel action $A(\theta) = -\ln(\sin\theta)$ with threshold markers $\theta = \theta_{\min}(A_{\max})$ for selected budgets.

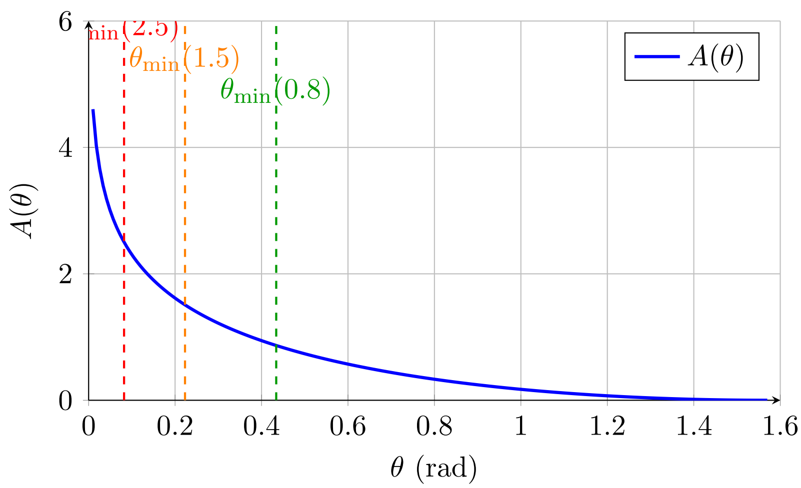

Figure 2: Kernel action and thresholds.